Earthbag Building Guide

By Owen Geiger

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Vertical Walls Step-by-Step

Excellence in Natural Building Series

ABOUT THIS SERIES OF BOOKS

Excellence in Natural Building, a series of how-to building books, provides innovative house plans and insightful information on the best, most efficient natural building methods: earth building, straw-bale, bamboo, thatch and sustainably harvested wood. The books in this series include detailed information and construction plans for a wide range of climates, expert advice on what works best, and an abundance of photos and drawings.

DEDICATION

This book is dedicated to the thousands of natural builders and designers around the world who are actively engaged in changing the course of our built environment for the better; those builders and designers who realize that a major paradigm change is required to prevent irrevocable environmental catastrophe; those builders and designers who strive to provide affordable housing for all of humanity equitably.

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Excellence in Natural Building

Earthbag Building Guide:

Vertical Walls Step-by-Step

Owen Geiger
Geiger Research Institute of
Sustainable Building

7,000 sq. ft. school built for the President of Burundi; photo: Dr. Johnny Anderton of Eternally Solar / EarthBagBuild.com

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South African earthbag; photo: J. Kennedy

Foreword

We have learned much about earthbag building over the last few decades through research, trial and error and sharing of information. It is becoming increasingly clear what works best and why. While other books have largely focused on introducing natural building methods, it is time to pull the most practical ideas together and take this movement to the next level.

Our environment is at a perilous crossroads and all of us need to do more to reduce energy consumption and live more lightly. This book and others in this series aim to showcase current best practices and encourage mainstream use before the Earth is irreparably damaged.

Another major goal of *Excellence in Natural Building* is to empower those in need of housing. Natural building has the potential to play a major role in addressing the current housing crisis. Approximately 1.2 billion people lack adequate shelter, with over one hundred million who are homeless. Natural building is the logical solution. Anyone can obtain safe, debt-free housing using local, natural building materials. By providing detailed how-to information, it is my hope this book makes a significant contribution toward solving the world's housing problem.

-Owen Geiger

About the Author

Founder and Director of the Geiger Research Institute of Sustainable Building (www.GRISB.org), Owen Geiger has a Ph.D. in Social and Economic Development. Dr. Geiger is an engineer and author of dozens of articles on affordable, sustainable building. His 30-plus years of construction experience include extensive hands-on building, designing and inspecting homes, training employees and hundreds of workshop participants and managing housing projects as a licensed contractor. He currently teaches, works as a consultant on international building projects and develops online content for numerous popular natural building websites. His writing and designs appear in the Last Straw journal, Mother Earth News and other magazines, as well as GRISB.org, EarthbagBuilding.com, Earthbag Building Blog, Earthbag House Plans and the GRISB Sustainable Building Blog.

Geiger Research Institute of Sustainable Building

Mission: To promote sustainable building practices through research, training, education and consulting services.

The Geiger Research Institute of Sustainable Building is devoted to finding solutions to the world's housing problems. As our forests and other natural resources are depleted and as global climate change worsens, our mission becomes even more pressing. We believe the answer lies in helping others help themselves. Please join us in our efforts to create a more just, sustainable world.

"***If everyone makes a difference, the world will be different***."

Introduction

Earthbag building (sometimes called sandbag building) originated about 250 years ago to provide bulletproof and bomb-resistant shelters that could be quickly built for the military. In addition, sand bags have been widely used to control floods for decades. The same qualities that make earthbags useful for military and flood control purposes apply to building houses.

Earthbag requires just a few simple materials – grain bags filled with soil or gravel, barbed wire and tools like shovels and buckets. A small shelter can be built for as little as a few hundred dollars. It is one of the lowest cost sustainable building systems in the world.

People are discovering that in addition to being sustainable, earthbags are safe, quiet, durable, nontoxic, rodent proof and resistant to bullets, floods and fires. When properly designed, earthbag structures can withstand hurricanes and earthquakes. Because of this, builders, NGOs, research institutes and government agencies are using earthbags in affordable clinics, schools, emergency shelters and disaster resistant housing. Examples include earthbag schools in the Philippines, Haiti and Sierra Leone, a clinic in Haiti, an eco-resort in Uganda, a ranger station in Utah, a temple in Thailand and orphanages in Honduras, Belize, and Nepal.

College students build a Kentucky park building; Photo: E. Bellamy

Earthbag, like geo-textiles used for retaining walls, is being engineered to work in the most challenging settings. Brandon Ross, P.E. and the University of Florida chapter of Engineers Without Borders has completed wind testing of an earthbag wall. The completed wall withstood out-of-plane dynamic pressures up 30 psf and quasi-static pressure up to 60 psf. More information on that project can be found here.

In September 2010 Precision Structural Engineering, Inc. made their engineer-approved earthbag system public. This generous donation of time and resources was intended to help rebuild Haiti, but it was also a major turning point for earthbag around the world.

Perhaps the most distinctive aspect of building with bags is their adaptability. Earthbags work equally well for domes or vertical walls and for rectangular or free-form, curving structures. This manual includes the special information needed to build different types well. It brings the best construction and reinforcement techniques to new builders now starting projects as well as expert advice for those seeking to become master builders.

Earthbag Compared to Other Earthen Techniques

To build well with earthbag one should understand how it differs from other earth materials. CEBs (compressed earth blocks) are a type of sun-dried hand or machine pressed brick used to build thinner walls than earthbag. Cob is solid, hand packed clay mixed with sand and straw. It is much more labor intensive and time consuming than earthbag. Rammed earth and adobe are both widely accepted earth building materials and are the most similar to earthbag.

Rammed Earth

This technique takes lightly moistened fill containing a small proportion of clay and pounds it into a solid, densely compacted and extremely durable monolithic wall.

Earthbag and rammed earth are very similar. Both use earth that has been tamped solid, but earthbag buildings use polypropylene bags or tubes instead of expensive forms. Since they are so similar in composition, it is likely that earthbag houses, like ancient rammed earth structures, will last for a very long time – possibly thousands of years.

Adobe

Adobe uses sun-dried earth blocks laid in courses with earthen mortar. Adobe ruins are scattered across the American southwest. After decades or centuries of neglect, when roofs have long since rotted away, adobe walls are still standing. Clearly, adobe is pretty tough stuff.

Adobe has become a luxury building method in the developed world. Many engineers, builders and building inspectors are familiar with the special requirements of adobe buildings. This type of construction has been thoroughly tested and is now widespread in many regions.

Earthbag

Earthbags are large, densely packed earthen building blocks. Although earthbag building has not yet been as thoroughly tested as either rammed earth or adobe, there is compelling evidence that earthbag is stronger than adobe.

Earthbag's soil fill is tamped, not just poured, adding strength by eliminating pore space and realigning clay platelets to bring them into intimate contact with each other. Also, solid weave poly bags and barbed wire add significant tensile strength. The barbs are embedded into the hardened soil between each course, as well as hooked on the bags themselves. This system can absorb more vibration than the brittle earthen mortar holding adobe together. Third, reinforcing steel is easier to add to earthbag than adobe, and forces concentrated in the rebar are shared by the matrix of bags and wire.

If builders follow the simple recommendations in this manual, earthbag buildings can be extremely strong – certainly far stronger than the mass produced housing being built today. This strength is similar to that of sand bag munitions structures that protect servicemen today.

"Militaries around the world…use sand bags to construct barriers to prevent propagation of munitions explosion. That is, large amounts of explosives are stored in large bins (the size of classrooms) made of sand bags. …If the munitions in one bin explode, the walls prevent the propagation of explosion as it is an excellent isolation that can absorb the blast. No rock infill was used and no metal bars were allowed."

– Engineering expert, University of Delaware

No other earth building system can absorb forces like this. Adobe and rammed earth have been the forefront of earth construction. Now many are beginning to choose earthbag for its strength and low cost.

EARTHBAG BEAUTY

Many people choose natural building materials to save money or energy, but nothing beats the warmth and rustic beauty of natural materials. Natural materials have a way of seamlessly blending everything together and turning a house into an inviting, nurturing home.

This brings up an interesting point. What building materials do the rich typically use to build their homes? What materials would you choose if you had nearly unlimited financial resources? Wood paneling or sheet rock? Marble counters or plastic laminate? Tile floors or vinyl? Berber wool rugs or synthetic? Slate or asphalt shingles? Timber frame or stud frame? Thick walls or thin?

Just look around and you'll see the answers are obvious. Most people choose natural materials when they can afford them. There are multi-million dollar adobe and rammed earth houses that demonstrate the beauty of natural materials.

Inside and outside details of Owen's simple earthbag roundhouse

Kelly and Rosana Hart's earthbag house is one example of earthbag beauty. Made almost entirely of locally obtained and natural materials, it has been featured in at least 10 books and magazines. Everything draws the eye and invites the touch, from earthen floors to peeled timbers, custom pine cabinets, a stone shower and hot tub and built-in benches.

Arched and round windows overlook the surrounding mountains in all directions, but also allow for passive solar heating. Its walk-in 'cool pantry' uses no electricity, but earth-berming keeps it a fairly steady temperature year-round from about 36 degrees Fahrenheit to about 65 degrees in summer (2- 18 degrees Celsius).

Because of the natural insulation provided by the volcanic gravel (scoria) in the earthbags, the Hart home remains comfortable even in Colorado winters at nearly 8,000 feet above sea level.

Other projects around the world show the incredible creativity of earthbag builders. Ranging from large homes to tiny sheds, many vertical wall buildings illustrate the versatility of earthbags. See the resources section in the Appendix for websites with examples of earthbag buildings. So here's the good news for the rest of us: build your own home using low cost building methods such as earthbag. Build in stages if necessary and pay as you go.

The Hart home; photos: K. Hart

Jesse Loving's earthbag house; photo: Jesse Loving

You don't have to be rich to surround yourself with the beauty of natural materials.

PART I: PLANNING

CHAPTER 1 – Dirt Cheap Shelter

The key to low-cost housing is owner-builder involvement, locally available natural materials like earth for walls and floors and small diameter wood for roofs. Using natural materials wisely can reduce impacts on the planet and future maintenance costs as well.

Earthbag construction: Earthbag building can be done very simply and for very little money. Almost all the materials and supplies can be obtained for free or next to free. If you use earthen plaster under wide roof overhangs, you can achieve true dirt cheap construction.

Tamped earth floors: Earthen floors, which have lasted for over 600 years, don't require wood framing, off gas toxic chemicals or need to be replaced like carpet or linoleum. Tamped earth floors are faster drying and look great under a simple oil sealer.

Small diameter wood: Many forests are choked with small trees. Because this inexpensive wood is round, it is naturally stronger and good for trusses, posts, beams, rafters and more.

Earth-sheltered spiral house

ESTIMATING EARTHBAG HOUSE COSTS

Earthbag walls can cost as little as 20-25% of the cost of concrete block walls.

The quickest cost estimate starts with a rough idea. $10- $12/square foot is as cheap as you can build. $10 per square foot is how much it costs in the developing world for laborers to build a simple earthbag building without much wiring or plumbing. In colder climates with more insulation, air-tight windows, wiring and fixtures $12 per square foot plus extras may be the lowest price if you build most of it yourself. Add to this the land cost, development costs (well, grading, road), labor costs and building fees. Then add extras like radiant heat, better windows, tile counters, or cement floor. Reinforcement for high seismic risk areas or to meet strict building codes also increases costs.

To make a more accurate cost estimate for a small house, add up the number of each component needed, and multiply it times a realistic cost from building supply stores. Add on fixtures, tool rentals, building department fees, and supplies. Then add about 5-10% extra to cover unexpected expenses.

Local contractors may have helpful square foot costs for labor and material of roofs, floors, insulating, windows, or kitchen and bath fixtures. Add on any labor costs if you will hire help building earthbag walls, or installing plumbing or wiring. If this is your first building, ask a pro to correct your estimate.

The number of bags needed for your building will influence how long it will take to build. Three ordinary people should be able to build 12 square feet of wall in about an hour, or a 4' long wall about 3' high. Experienced contractors and strong workers can build earthbag more quickly.

How Many Bags? By Kelly Hart

Find the total square footage (or m²) of the wall by multiplying the length times the height. If your wall is curved, either make a scale drawing and measure it, or in the case of a circle use the formula Length = 3.14 x the diameter. You could deduct the size of the windows and doors, but for ordering bags I usually don't because it is better to overestimate the bags. You usually need some extra partial bags to maintain running bond.

It depends on the size of the bag how much square footage it will cover. The standard bags that are 18" x 30" (46 x 76 cm) empty measure roughly 5" x 20" (12 x 50 cm) when laid in a wall and compacted. Each bag makes about 0.7 of a square foot (or 0.06 m). Each square foot will take 1.43 bags and each square meter 16.7 bags. See page 19 for more information on other bag sizes.

For standard bags, multiply the face area of the wall by 1.43 to get the total number of bags needed. A 100 square foot wall (8' high and 12'6" long) would require 143 bags (2.45m x 3.8m = 9.3 meters²).

The soil needed to fill bags will be a little larger. Each bag can use 0.8 cubic feet of soil dug or delivered or more, before compacting (0.074 cubic meters). Footings and wall bottoms should use either gravel or else add a bag of Portland cement to each 25 bags of earth fill.

$10 per Square Foot is Possible

Low cost is a big reason for the growing popularity of earthbags. A shelter can cost less than $1,000. A non-toxic and comfortable small home would outlast most wood-framed houses but cost $2,000- $5,000 if the owner builds with found or discounted materials.

My 2010 roundhouse

Build more cheaply by doing a little at a time. This requires planning ahead for future doorways and connections, but can produce a debt-free home. Avoiding building codes will save more than any other factor. Although there is a basis for a code exemption for Alternative Materials, some counties (especially in highly populated areas) make the process so difficult that it may not be worth the trouble.

Also every additional feature (window, door, linear foot of plumbing or wiring, light fixture, etc.) and every additional square foot of roof, or extra surface on a complex roof, adds a lot to overall costs. The larger, more complex and more functional a design is, the more expensive it is per square foot. A simple building can be inexpensive. So if cost is important, simplify!

CHAPTER 2 – Choosing a Plan

Many people seek a house plan that looks right – the right size, with a shape and style that appeals to them. They then try to save money or build sustainably by choosing good materials to build it.

Learn as much as you can about codes and building restrictions in your area before buying land, then let the site and the type of energy systems influence the plan. Solar heating or cooling requires special building shapes, while alternative water technologies like solar water heaters, greywater systems and composting toilets are easier to include when added early to the list of goals. Earthbag is also stronger when the type of layout and dimensions suit the type of soil and local conditions.

2-1: Orphanage Site Plan; P. Stouter

PLANNING FOR SUSTAINABILITY

Choose a plan developed for the objectives that you find important. Earth materials used on site produce no pollution or waste (if simple measures like siltation fencing are installed). Almost 28% of all US landfill debris is produced by new construction. Buildings made of earthbags have very low embodied energy, since processing soil for buildings requires only about 1% of the energy needed to manufacture and process the same volume of cement concrete. 'Earthen construction has the best Life Cycle Assessment Costs of any building material/process known to man'.[1]

Earthbag houses contain thermal mass that can help moderate interior temperatures naturally. They can also be well-insulated. Most earthbag buildings can be designed to meet or approach zero energy goals, producing as much energy as they consume. Plan to fulfill strategies like these:

NON-TOXIC AND NATURAL BUILDINGS

- Design for safety and health
- Small size to conserve resources and energy
- Daylight for mental health

BUILDING AND OUTDOOR SPACES SHAPED FOR YOUR CLIMATE

- Let sunlight in (for heating) or breezes (for cooling)
- Properly sized roof overhang blocks summer sun but allows winter sun in
- Porches, courtyards, and patios located for comfort, views, and convenience

SUSTAINABLE TECHNOLOGIES

- Generate energy naturally
- Capture roof-water
- Cleanse and recycle greywater
- Grow food

2-2: Farm Guesthouse; earthbag plan by Owen Geiger

Avoid high maintenance and utility costs. Conserving energy always saves money and can create the fastest return on investment of all your building expenses. Although earthbag buildings have less air infiltration than wood buildings, extra care in sealing and insulating will still pay off. See the *Earthbag Design Guide* for more help with zero-energy planning and energy conservation.

PLANNING FOR STRENGTH

Those located in a region with high risk of earthquake can benefit from the flexibility of earthbag buildings. For those in regions affected by hurricanes and tornados, massive earthbag walls resist wind forces well. Earthbag walls are strong if they are designed and built carefully for local hazards. Good footings and a strong bond beam on top are important. **Any building material can create dangerous buildings if poor construction techniques or unsuitable plans are used.**

General rules of thumb for adobe can guide earthbag builders in low seismic risk areas. Leave three feet (1m) between openings like doors or windows and corners. A full discussion is included in the companion book *Earthbag Design Guide*. Home plans already designed to meet Zero-Energy goals and to use earthbag's intrinsic strengths are on my Earthbag House Plans website. You could also ask the author about a custom plan.

WORKING WITH ENGINEERS & ARCHITECTS

Earthbag domes have been approved in high seismic risk areas because of testing observed by code officials for Cal-earth in the past. Because vertical earthbag walls in rectangular buildings do not share the same formal strengths, buildings for areas where construction is highly regulated may need an engineer or architect's seal on the plans to be approved by local building departments.

In areas with more risk of earthquakes or tsunami or storm flooding, careful custom structural design can also minimize the cost of reinforcements needed for safety. Earthbag can be built with exterior rebar, as a type of confined masonry, or using cement-stabilized and specially reinforced buttresses. Precision Structural Engineering has information online, or see the *Earthbag Design Guide*.

[1] http://www.earthcomegablock.com/Advantages.htm

CHAPTER 3 – Tools

Since earthbag only requires simple tools, you may already have most of these. See the short video about Earthbag Tools at the Naturalhouses YouTube channel.

3-1: RECOMMENDED TOOLS

Shovel, hammer, chisel, scrap steel, crayon or pen, string, hose and stakes to make a water level, tampers, corner guide, knife, tape measure, pliers, plastic plasterer's hawk, plaster trowels, hose, long level, two gallon buckets, four gallon bucket chute, hoes, slider.

3-2: ABSOLUTELY NECESSARY TOOLS

A hoe, good tampers, wood stakes, and a few buckets are really useful. A 25' (10 m) tape measure and a 4' (1.2 m) long level or water level are absolutely necessary. Knives, pliers and a hose for wetting soil mix will also help. If you don't have a bolt cutter, a chisel and scrap of metal can cut barbed wire. A nail and a string can make a plumb-bob. A hawk holds plaster while applying it, and different shaped trowels work well in different locations.

Other tools not shown include: gloves, tarps, hack saw, markers, carpenter's pencils and scaffolds.

A small sledge hammer is best for driving rebar reinforcements into the walls.

Hoes

Hoes are perfect for filling buckets with soil. Grub and grape hoes are better than shovels for digging clayey soil such as road base or subsoil. One of these hoes can cut right into the soil and pull the material into buckets without lifting.

3-3: Grape hoe (Left), grub hoe (Right)

They may be the world's most widely used garden and farm tool. Grub hoes are slightly larger and therefore better suited for digging difficult soil. This size works best for digging foundation trenches, but is a bit heavy for using all day long. The lighter weight grape hoe is a little shorter and is perfect for filling buckets with soil.

Buckets for Soil

Most builders prefer heavy duty 2-gallon plastic buckets (8 liter) for filling earthbags, the same kind used for bucketing cement. Some prefer to use metal cans, but work moves faster with this size bucket.

3-4: Passing soil with a 2 gallon bucket

Each standard sized bag (about 18" x 30" when empty or 46 x 76 cm) takes about four or five of this size buckets of soil. Perhaps you can find free plastic buckets and save money. Some people use partially filled 5-gallon buckets (19 liter spackle or paint buckets), although they're more awkward.

Video: ***Cement Buckets***

Special Earthbag Tools

Bucket Chute

The easiest way to keep earthbags open during filling is with a bucket that has the bottom cut off to act as a funnel. A regular bucket is sturdy enough. Cut off the bottom inch with a saw and sand edges to remove burrs. A 4 or 5-gallon plastic bucket (15 or 19 liters) fits perfectly in 18" wide bags or tubes (46 cm).

3-5: Stainless steel bucket chute

For about $10 you can take the bottom off of a metal bucket of the same size and add a leather shoulder strap, to take weight off your arms. This is a good method for filling tubes. Some may prefer a bucket chute without a strap that can be set aside more easily.

Make sure your chute fits the sizes of bags or tubes you will be using. 17" wide bags (43 cm) or most mesh tubes will need a slightly narrower chute than 18" wide bags or tubes. A slight funnel shape that works well with a stretchy mesh can be made by cutting, overlapping, and pop-riveting a plastic bucket.

Video: ***Bucket Chute***

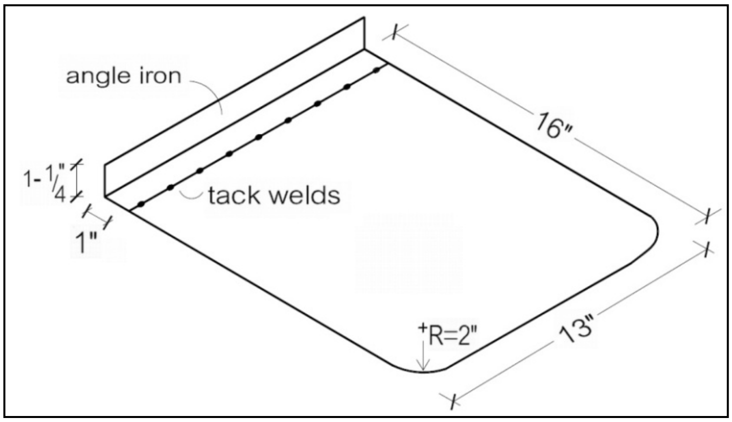
3-6: Straight and slanted chutes; photo: P. Stouter

Earthbag Stand

Some people use metal or plastic stands to hold bags while filling as they can reduce back strain. Try it to see what you prefer. Others fill earthbags in place on the wall with just a little care to keep bags vertical without added support. In a recent poll on our blog most people said they do not use a bag stand because working without it means one less tool to move again and again.

Sliders

A slider makes it easy to place bags on the wall without getting hooked on the barbed wire. Bags are filled and moved into place on the slider and then the slider is removed with a quick pull.



3-7: How to make a slider

My favorite slider is made from a sheet of 16 gauge steel about 13" x 16" (33 x 40 cm). Tack-weld a piece of 1" by 1 1/4" angle iron (2.5 x 3.2 cm) on one end for a grip and then weld the back edge. Radius the front corners 2" or so (5 cm). Grind off sharp edges, remove any rust with sandpaper and then spray paint to protect the metal. Recoat after each project since these sliders really take a beating.

A simpler slider can be made by flattening galvanized stove pipe or using a 16" x 20" sheet (36 x 50 cm) of sturdier 14 gauge stainless steel. Bend the end of the slider 90 degrees for the grip. A metal shop can do this easily.

Some builders prefer a wood slider with 1" x 2" skids so that it doesn't touch or flatten the barbed wire.

Video: ***Sliders***

Barbed Wire Stand

One technique for handling large, heavy rolls of barbed wire is to make a dispenser with a pipe and scrap wood, or just stack a few blocks on each side to hold the pipe.

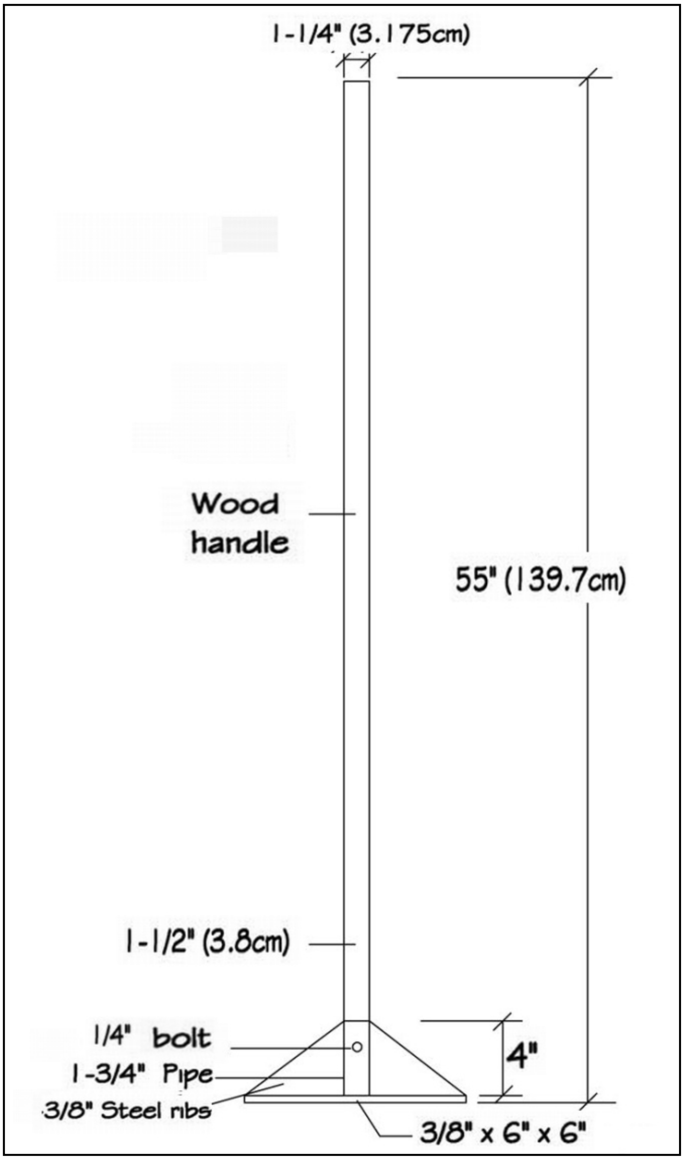
3-8: Wire stand

My Favorite Tamper

Tampers for earthbag walls from a building supply center are often less than ideal with short handles. Many earthbag builders make their own tamper bases from concrete or steel. The tamper design described here has been more popular at workshops than clunky concrete ones. It costs about $5 to make. Often welding shops have metal scraps for this simple design.

<u>Supplies for a Metal Tamper</u>
Quarter inch hex head bolt (6 mm)
Steel plate for base 3/8" (95 mm) thick:
One 6" x 6" bottom piece (15 cm square)
Four angled ribs made of two 4" x 5" pieces (10 x 12 cm)
4" long, 1-3/4" diameter pipe (10 cm long x 44 mm)
1 -1/2" diameter wood (38mm) handle

Weld the pieces together and drill the pipe as shown to accept a bolt to secure the handle. Grind the edges, remove any rust and oil and apply your choice of spray paint. Wood handles don't get as hot as metal and have a more comfortable, natural feel. Sand the wood to eliminate splinters and round the end slightly. Fit the handle to the pipe and pre-drill through the wood. Several thin coats of tung oil will protect the wood.



3-9: Plan for a welded tamper

A 45” (110 cm) version is used to lightly tamp bag contents during filling. A longer 55” (140 cm) can apply greater force when tamping walls. Bigger, stronger workers may prefer larger sizes like 10” x 10” to speed tamping. Adjust sizes to fit your needs. It’s convenient to have different sizes, enabling more workers to help out and choose the best size for them.

3-10: Makeshift and store-bought tampers; photo: P. Stouter

Some builders use tampers made of wood posts or logs. A round concrete tamper or a section of 4 x 4 can fit into a bag more easily for pre-tamping while filling.

Video: ***Tampers***

TUBE FILLER

Since it is somewhat awkward filling tubes, it helps to have a good system worked out. Here’s a worthwhile stand that was demonstrated at the 2007 Natural Building Colloquium in Texas. Information on this tube filling machine is available at the Natural Building Colloquium of Texas and a close-up view at the Earthbag Building Blog. This homemade metal frame can be moved on the wall as the tube is filled. A sturdy stand and good scaffolding could even allow a single builder to lay tube alone.

3-11: Homemade tube filling machine

One good, inexpensive method of filling tubes is with a round form used for concrete footings. These cardboard tubes are sold by various companies such as SonoTube. Simply slide the poly or mesh material over the cardboard tube and hold in position as another worker pours in the soil.

Optional Tools

Temporary Scaffolds

Use straw bales, milk crates or pallets next to walls more than 4' high (1.2 m) so workers on wall tops have a safe place to jump if they lose their balance. Pallets slanted against the wall can also act as a short ladder.

3-12 & 3-13: Pallets as scaffolding; photos: E. Bellamy

Power Tools

Power tools can save time and energy. Although they are not necessary, whether you are building yourself or paying labor, less time usually does mean less cost.

Additional carpentry tools like power saws, power drills and nail guns are very useful for making door or window bucks, anchors, lintels and forms for concrete.

A portable mortar mixer is a great help to prepare stabilized bag fill, plaster, or stucco. It can produce smoother, higher quality plaster mixes if it is available.

Power tools can also be used for the finish coating on bag walls. A ceiling texture sprayer can apply a paint and fine sand layer that will protect bags from UV decay and allow the plaster to stick well. A mortar sprayer can apply plaster in thinner layers.[1]

3-14: Mortar sprayer; photo: N. Scheid

[1] Mortar sprayer available from Nolan Scheid at his company Mortar Sprayer.com.

CHAPTER 4 – Supplies

The supply list will vary somewhat depending on whether you use bags or tubes, the type of stabilized or unstabilized fill and how you close bag ends. Use this checklist to start planning.

Video: ***Earthbag Supplies***

4-2: 500 bags — enough to build an 18' diameter roundhouse

4-1: SUPPLY CHECKLIST	
Quantity	Item
Basic Supplies	
	Solid woven poly and/ or mesh bags or tubes
	4-point barbed wire
	Soil for bag fill
	Gravel
	Wood or metal scraps for anchors
	Steel rebar (usually 1/2 inch/ D12)
	Fasteners: nails, screws, bolts
	Materials for bond beam
	Materials for roof
Optional Supplies	
	Cement for footings if required
	Sand or clay to modify bag fill mixture
	Cement or Type-S lime to stabilize soil
	Wood, cement, or metal for lintels
	15-20 gauge galvanized tie wire
	Nylon cord and large sewing needle
	Plaster supplies: lime or cement, sand, etc.
	Fishnet, chicken wire or mesh for plaster

MATERIALS FOR BAGS OR TUBES

The fabric in earthbag walls provides a form to enclose soil as it is placed, tamped and dried. It can be either a tube or bag made of several different materials.

Earthbag was originally developed for solid polypropylene weave fabrics. Solid-weave poly tubes or bags manufactured to hold grain add more strength to buildings than mesh bags or tubes. They require barbed wire between courses to increase bag to bag friction, but they also interlock with the wire and rebar reinforcement. Solid fabric protects fill from mechanical damage and can also permanently contain loose fills (earth without clay, gravel, sand, or alternative plant or waste materials like rice hulls). They may resist soaking damage somewhat better than mesh tubes.

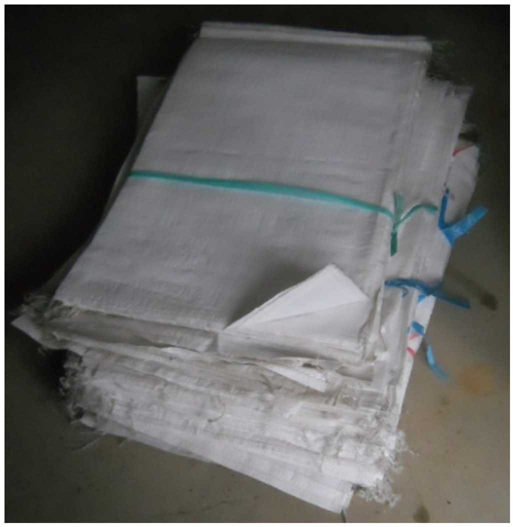
Table 4-3: Bag Material By Fill and Strength Requirements		
	Buildings in Non-Hazardous Regions	*Buildings in Hazardous Regions*
Gravel fill	**Solid Poly**	**Solid Poly**
Sand or loose fill	**Solid Poly**	**Solid Poly**
Earthen fill with clay	**Solid Poly** **Mesh** (Burlap only with cement stucco on a strong reinforcing mesh)	**Solid Poly** (Unknown whether mesh fabric will help to contain walls in earthquakes)
Stabilized fill	**Solid Poly** **Burlap** **Mesh**	**Solid Poly**

Choosing Fabric Type

The strength of poly bags is important for earthbag buildings in hazardous regions. A standard weave is 10 x 10, 850 denier. There is a lot of information on the web about solid-weave poly bag characteristics.

> "*Pound for pound, polypropylene is stronger than steel, and when woven into a fabric it creates a lightweight, durable material with applications in many industries.*" NYP Corporation[1]

> "Poly bags are low cost, flexible and high strength, available in a wide range of sizes and strengths, tear and wear resistant, 100% recyclable, resistant to alkali and acid, corrosion resistant, resistant to fungal growth, virtually unaffected by water and atmospheric moisture, and don't absorb water."- Multiple websites



4-4: Several hundred solid-weave poly bags

Mesh Fabrics

Recently mesh tubes and bags manufactured for erosion control or shipping fruit and vegetables have become a building alternative. The mesh material is lighter and takes less space so that rolls or bags are cheaper to buy and ship than solid materials. The mesh tubes are also easier to work with than solid

poly tubes. However, mesh properties vary from source to source. Some mesh does not shrink. Buy samples and make some test earthbags to determine what works best.

4-5: Raschel (left to right) and leno weave , vexar and crocheted mesh

Mesh material seems to have good bag-to-bag friction. For small vertical-wall earthbag buildings in areas with low risk of natural hazards builders can avoid the time, cost and difficulties of using barbed wire. Barbed wire is necessary in all domes for tensile strength. Barbed wire, other wire mesh or geo-grid reinforcement can add extra strength needed in some vertical wall buildings for hazardous and non-hazardous areas.

Mesh material enables earth fill containing plant materials to dry quickly and avoid mold damage. For non-hazardous areas this light clay fill can create walls that weigh less and insulate. Hyper-wattle is an infill wall material made by filling 6”- 10" (15- 25 cm) diameter mesh tubing with clean straw and dipping in a strong clay slurry. It may be strong enough to be a bearing wall for small single story buildings with light roofs if a grid of light bamboo or wood is tied to the interior mesh surface.

Mesh material enables earth fill containing plant materials to dry quickly and avoid mold damage. For non-hazardous areas this light clay fill can create bags that weigh less and insulate.

MESH FOR HAZARDOUS AREAS?

4-6 (below): Placing a leno mesh earthbag

4-7 (bottom): Stronger crocheted mesh for erosion control

Because mesh bags or tubes contain only a portion of the strands that give solid bags their strength, most mesh fabrics will probably not be safe for most buildings in hazardous areas. Some high-quality mesh for erosion control has 85% the tensile strength of solid poly weave bags. The use of these fabrics in buildings that require higher strength should be evaluated.

The mesh material also allows a wall of earth with clay to unite through the bag. This may not be desirable in hazardous locations. A wall of separate bags that can flex should be able to absorb earthquake vibrations with less damage than a stiff or monolithic wall that cannot flex as much.

BURLAP BAGS

Burlap is made from jute, a natural fiber. However, most of the burlap in the U.S. (and likely most other countries as well) has been treated with unhealthy hydrocarbon

mold inhibitors. Some people have an extreme allergic reaction to this chemical treatment. In addition, burlap bags are more expensive and less durable than poly bags. For these reasons, poly bags are used by most earthbag builders, except for those in non-hazardous areas who want to let the bags decay after construction to expose the fill material.

Some untreated burlap rolls could be home-sewn into tubes. Bags made for coffee, grains, nuts and other food products may also be all natural and it is possible recycled bags could be found. Recycled bags made of natural fibers have the least environmental impact of all bags. The drawbacks include added effort tracking them down and extra cost and labor if the fill must be stabilized.

BAGS OR TUBES?

4-8: Honduran orphanage; photo: E. Adalow

Many builders prefer bags to tubes because recycled or misprinted bags are more sustainable and lower cost. But polypropylene tubes are also very popular. Because tubes can be laid in 8' lengths or longer, they are quicker to build and can save plastering time and materials. Creating tightly curving walls or domes is much simpler with tubes. For novice earthbag builders, the plaster for smoothing lumpy walls can be a significant cost.

Tubes come in rolls up to 11,000 feet long.
Although the growing consensus is that poly tubes are faster than working with bags, the type of work is different. Tubes are usually built by teams of at least three, while bags can be easily built alone. The table that follows shows the advantages and disadvantages for each.

Mesh tubes are less expensive and faster to build with even than solid-weave poly tubes. Since mesh tubes lack some disadvantages of poly tubes, they are becoming popular in situations that do not require the strength of solid weave material. Check the Earthbag Building.com resource list or look on the Earthbag Building Blog for up-to-date recommendations about types and suppliers of mesh. Many builders prefer bags to tubes because recycled or misprinted bags are more sustainable and lower cost. But polypropylene tubes are also very popular. Because tubes can be laid in 8" lengths or longer, they are quicker to build and can save plastering time and materials. Creating tightly curving walls or domes is much simpler with tubes. For novice earthbag builders, the plaster for smoothing lumpy walls can be a significant cost.

Tubes come in long rolls. Although the growing consensus is that poly tubes are faster than working with bags, the type of work is different. Tubes are usually built by teams of at least three, while bags can be easily built alone. The table that follows shows the advantages and disadvantages for each.

Mesh tube walls are less expensive and faster to build even than solid-weave poly tube walls. They are becoming popular in situations that do not require the strength of solid weave material. Raschel mesh tubes may be the least expensive. A raschel mesh tube that can stretch to 20- 22" wide when flat (the "layflat" dimension) will form a standard 14- 15" wide earthen wall. 18" wide raschel mesh will form a 13" wide wall, adequate for 4- 6' height walls.

Mesh tubes shrink slightly in length as they are filled. You will need 30% more raschel mesh than your wall length. Vexar and crocheted mesh can shrink more, some require up to 80% extra length when filled firmly. Remember that more courses will be needed with a 3”- 4” height per course.

4-9: COMPARING TUBES AND BAGS

	Solid Weave Tubes	Mesh Tubes	Bags
Quick to Build?	✓	✓✓	Slower, hard to shape tight curves or domes
Available Materials?	Somewhat uncommon higher shipping costs or delays	Somewhat uncommon higher shipping costs or delays	✓✓
Cheap Materials?	Higher	✓✓	✓
Easy to plaster?	✓	✓✓	If walls are built with extra care
Sustainable?	✓ Less fabric waste	✓✓ Little material	✓✓ If recycled bags
Workers Needed	Need 3-4	Need 3-4	1+
Details	Can form a ‘rainbow arch’ of stabilized fill. Takes time to scrunch tubes onto chute.	Not for sandy soils, gravel, or hazardous areas	May be best for earthquake hazard. Takes time to close bags neatly

WHAT BAG SIZE IS THE BEST?

The most common size bag for earthbag building is about 18x30” measured when empty (46 x 76 cm). These bags are used to store 50 pounds of grain or feed (22.7 kg). When filled, this size creates walls about 15-16” wide (38- 40 cm) and 20-24” long (60 cm). This is a good size for earthbag building because they allow 8-12” of overlap between courses. These bags are not too heavy to handle,

weighing about 100 pounds (45 kg) when filled with moist earth fill. People who are less concerned with bag cost can use these standard bags filled partially, which weigh about 70 pounds, although this produces less bag overlap.

Bags of smaller dimension are easier to handle, but the more narrow the walls are, the less stable. The main problem with only slightly smaller bags like the common 17” x 27” ones (43 x 69 cm) is the fact that these bags are so short that only about 5” of overlap is possible without adding special long or short bags. See the *Earthbag Design Guide* for a discussion of methods for using these shorter bags. Some people want 24” long bags (when filled) that can be folded under instead of sewn or pinned shut. Longer 18.5”x34” bags are carried by some bag suppliers.

Even though earthbags are typically filled on the wall to reduce labor, there’s still a fair amount of sliding and aligning involved. Using larger bags requires a lot more effort to build and slows construction. The largest bag sizes are about 22”- 24” x 36” when measured empty (55- 60 x 90 cm). These larger bags are very useful for specialized applications such as basement walls, root-cellars and earth sheltering. Larger bags are more expensive and take more fill material than standard bags. The main problem is that they are very hard to move as they can weigh up to 150 pounds.

Video: ***Bag Size***

Bag Extras

Gussets

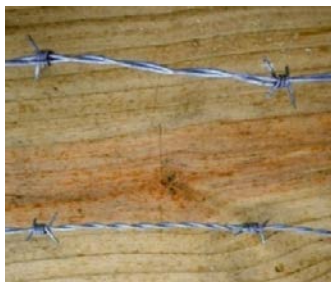
4-10: Gusseted bag corner

A gusseted bag has a tucked seam that eliminates bulging or protruding corners. Gusseted bags create neat, squared bag ends. Although not required for earthbag building, they can reduce plastering work by creating flatter wall surfaces. If gusseted bags are too expensive or not available in your location, bags can be turned inside out, or hand-tucked (called diddling), or protruding corners can be tamped in before plastering.

UV Protection

Some manufacturers offer bags with 1600 or 2000 hour UV protection. This can be well worth a little extra cost on slow-moving self-build projects or buildings in warm regions with intense sun exposure.

Barbed Wire



4-11: Barbed wire; photo: P. Stouter

All barbed wire used in earthbag walls should be galvanized, 4 point. Barbed wire keeps bags from sliding on courses below during construction and adds important tensile strength to hold walls together. High-tensile-strength barbed wire (shown at bottom) is lighter and less springy than the old-fashioned kind (shown on top), meaning it costs less and is also much easier and safer to use.

Important Supplies


4-12: Supplies include barbed wire, fasteners, galvanized wire, sheet metal for attachments, strong twine or cord and fishnet

Wire and Cord: Use a sturdy poly or nylon cord and/ or galvanized tie wire.

Mesh: Usually only used to underlay plaster at vulnerable door and window openings or as a building wrap in high seismic risk areas or when required by code. If fishnet or plastic net is available, they or alternative fiberglass stucco lath are preferable in coastal regions where salt in the air speeds corrosion of metals. In other regions chicken wire may be modest in price and easy to buy, or galvanized metal stucco lath can add significant strength.

Fill Material for Earthbags

Most earthbag builders use soil to fill bags. Alternative fill materials like sand, gravel, plastic trash, or plant based materials do not solidify like earthbags filled with a soil that contains clay. Sandbags are much harder to finish neatly at corners and can shift or slump in taller stacks. Buildings using alternative fills usually need extra reinforcement, extra temporary bracing, and a strong structural skin of reinforced plaster.

The strongest and most stable bag fills include many particle sizes from sand to clay. Most subsoils (the clay/aggregate mix that lies below the topsoil) are adequate as fill and are found at or near the site. You can add sand or clay to modify them if needed. The most common mix is about 25-30% clayey soil and 70-75% sandy soil, although precise ratios are not necessary. You need soil with enough clay to bind the aggregates together. Soil with too much clay can be used but is harder to dig and fill bags with, must be kept dry enough to handle and can slump if too wet.

Site-based soils may need some testing to determine whether your soils will work well, or how much clay or sand must be added to improve them. It is easiest to test a dried sample of soil.


4-13: This soil is too sandy for earthbag

Add just enough water to squeeze it into a ball in your palm. Sandy soil will not hold together, even with more water. If the soil holds together, drop a 1 inch (2 cm) ball from 5’ height (1.5 m) onto a hard surface. A good earthbag soil with just the right amount of water will split into two or three pieces or crack. It should not be wet enough to leave a wet mark where it hits. This test can also be used as frequently as needed while building to see that soil is mixed well and moisture levels are correct.

If your soil only cracks but does not split apart, it has a lot of clay. You should probably see how small of a snake you can roll of it 4” long (10 cm). If you can hold up a 4 mm roll or smaller by its end, it is a plastic clay. You should dry some to see if it is a soil that shrinks and swells. Spread it out 3/8 inch thick (1 cm) on a 4” square (10 cm) piece of oiled metal. More information about soil tests is available in an eBook online. [2]

4-14: This drop test is good soil for earthbag

Road base, crusher fines (reject fines) or fill dirt (low cost subsoil available from excavation companies) delivered by the truckload can save many hours digging and moving soil by hand. Gravel is typically used in rubble trenches and lower courses of earthbags. Bags filled with gravel, sand, or sand with other materials are not damaged by moisture.

4-15: This drop test soil may have too much clay

Videos: ***Soil Preparation***, ***Clay/ Aggregate Ratio of Soil***, ***Adjusting the Moisture Content***

ROAD BASE

Road base is usually a mixture of clay and gravel designed for road building throughout the world. Local engineers mix and test it to withstand extreme loads of trucks and cars. It should be a uniform mixture without clumps of clay, organic material or large rocks. Buy a small quantity and make one or two test earthbags to be sure you have the right kind of material.

4-16: Moistening road base

With road base, you can begin building right away. Road base is typically very inexpensive and many suppliers are usually available to meet demand. This often means a truckload can be delivered to your site in short order from a nearby supplier. Using road base also eliminates digging for soil on your land, preserving the natural beauty of your site, and since it is delivered by truck, you can have it stockpiled around the building site just where you need it. Freshly piled soil will be loose and much easier to measure, move and use than compacted soil.

CRUSHER FINES

Crusher fines are small particles of crushed rock leftover from rock crushing operations. Crusher fines are less expensive than larger, more valuable aggregates. The optimum mix consists of angular particles, in a distributed range of sizes from rock dust to 3/8” diameter (1 cm), with just enough clay as a binder. This is often called 3/8” minus. The harder the parent or source rock, the stronger the binders will be. The right combination of aggregates and binders will create natural soil cement. Like other soil mixes, order about 30% extra to compensate for compaction. As with any fill material, it is good practice to buy a small quantity and make one or two test earthbags.

Stabilizers for Fill

Sometimes builders add stabilizers like lime or Portland cement to earthbags to increase strength or prevent water damage. Often new earth builders are worried that walls will be too easily damaged. Earthbags placed above the level of drifted snow, water leaks, or rain splash do not have to be water-resistant. Earth walls last well under an 18” roof overhang (90 cm) minimum. Builders who have not worked with earthen or lime plasters may not trust ‘raw’ earthen fill. Tamp, dry and plaster at least two pure earth test bags. Place flashing over the top edge, and leave the plaster side exposed to sun and rain for a month. Find out how well earth works in your location before deciding to stabilize.

Testing for Compressive Strength

Engineers recommend 250 - 300 pounds per square inch (psi) compressive strength for adobe. Earthbag tests at a university laboratory by Bryce Daigle proved earthbags to be this strong. Some engineers ask builders to prove their bags are this same strength, despite the strong tensile network of solid weave poly bags and barbed wire. Informal tests cannot reach 250 psi on a whole earthbag because a standard bag would require a 90,000 pound weight. 250 pounds on one square inch is not the same.

Adobe builders often rely on simple tests. They expect a good soil block to not break when dropped on its corner from a 4 or 5’ height and a block spanning 10” (25 cm) to hold a man. Earthbag builders drive a small truck or car onto an earthbag. These can probably exert about 30 psi on the center of a bag. A tamped and dried earthbag crushed by pressure from a car tire is not strong enough. Adding clay to sandy soil or sand to heavy clay can increase compressive strength.

Choosing Stabilizers

Unstabilized bag fill that is soaked can lose volume as the clay particles dissolve out. Solid weave poly earthbags resist flood damage better than plain adobe, but earth fills can be damaged. Any bags subject to soaking from flooding, rain splash-back or snow should not rely on clay for strength unless they are stabilized to maintain their strength and shape when wetted.

Gypsum is a good stabilizer for sandy soils, improving strength and speeding drying time. Add about 10% of gypsum and 2% of lime by weight to make soil water-resistant (not waterproof).[3] Gypsum is produced at lower temperatures, using about 1/7th as much energy as cement and 1/5th that of lime.

Lime alone can be used to stabilize clay soils. Lime requires less energy to produce than cement, but it must be used in a richer mix than cement. Lime-stabilized soils maintain their breathability. A mixture proven effective in the lab is lime and four-day-old cow dung mixed 1:4:8 with sandy loam soil[4].

Earthen fill often needs only 4-6% Portland cement by volume to become water-resistant, though some soils can require 10-12%. Clay soils often need lime with cement. However, unlike clay, Portland cement stays humid and can wick moisture up into earthen walls. A bag fill with a smaller percentage of Portland cement will dry out better and retain more ability to moderate interior humidity. Test soil samples with different amounts of Portland cement and added lime, wood ash, fly ash (industrial waste)

or natural caliches. Stabilized earth blocks should keep much of their strength when wetted. See that a stabilized earthbag doesn't crumble or break easily when dropped while it is wet.

Because earthbag walls are thick, 4-6% of a stabilizer costs a lot. Stabilizing bag fill requires 0.5-1 cubic feet of stabilizer (usually a half to a whole bag of Portland) for each linear foot of 8' high wall. If possible, stabilize only the plaster. This takes only a quarter to half as much as stabilizing the wall.

ALTERNATIVE FILL MATERIALS

One excellent insulator can also form a structural bag wall. Scoria, also known as volcanic rock or lava rock, has good bearing strength and usually interlocks well enough to form a stable bag. Due to its volcanic origin, scoria is filled with tiny air spaces, making it a good insulator for dry locations. Kelly Hart pioneered the use of scoria-filled earthbags on his home and shop in Crestone, Colorado. The R-value of scoria is somewhat variable, but with 5" of paper-crete or light straw at R-2 per inch, scoria bag walls may be comparable to straw bale walls of around R-26 to R-30.[5] Scoria is inexpensive in many regions with active or dead volcanoes where it can be used alone as bag fill.

Builders are experimenting with a wide range of fill materials. The table below compares the approximate R-values of three sustainable insulating materials that could be used in poly bags. All of these materials are natural, lightweight, easy to work with and non-toxic. Rice hulls are naturally fire- and rot-resistant and do not attract insects or vermin. Plant based materials like rice hulls or wood chips or straw are often cheaper than mineral types of fill. Video: ***Rice Hulls***

Table 4-17: Insulation Values of Alternative Fill

Material	R-value/inch	R-value/15"
Rice hulls	3	45
Perlite	2.7	40
Vermiculite	2.13 to 2.4	32 to 36

Perlite and vermiculite are fireproof, rot proof and also do not attract pests. Because perlite is not adversely affected by moisture, it is good in bag fill in more humid climates, in earth-bermed structures and for below grade insulation. Unfortunately these materials are often costly.

These loose fill materials cannot form structural walls, but they can form a core within a structural skin of wire mesh and strong lime or cement plaster. Other loose fill materials that can form a core or infill material include rounded gravel, screened concrete rubble from collapsed buildings, sand, shells or plastic trash. New developments in bag fill are discussed in detail on the Earthbag Building Blog.

[1] Quote about solid weave bag strength from NYP Corporation.

[2] Free *Soils for Earthbag* booklet online

[3] Information about gypsum adobe construction and a report.

[4] Gernot Minke, *Building with Earth,* Birkhauser, Basel, Switzerland: 2006, page 42

[5] Discussion of scoria and paper-crete as insulation at Earthbag Building website.

PART II: BUILDING

CHAPTER 5 – Foundations

Reinforced concrete footings are the most common type in the developed world, although they often cost thousands of dollars. Concrete footings are not always necessary but work well on weak soils or in high seismic risk areas.

CHOOSING ALTERNATIVE FOUNDATIONS

Gravel bag foundation walls on gravel or rubble footings protect buildings from frost damage and are growing in popularity. Any of the following can be used as a base for alternative or conventional walls.

A one-story earthbag building weighs about as much as a two-story cement block building. It is a good sign if neighbors have a two story concrete block building without any foundation problems on the same kind of soil. If your soil is soft or swells, or your area experiences extreme cold, you may need advice from an engineer or architect to decide the cheapest way to make a good foundation and how wide and deep it should be.

RUBBLE TRENCH FOOTING

The easiest, cheapest footing is a rubble trench, popularized in the US by architect Frank Lloyd Wright. A gravel and rubble trench, standard in warm climates, acts as both drainage and footing on soils of good strength. This is common for earthbag buildings with a flexible gravel bag foundation wall on top.

GRAVEL BAG FOUNDATION WALL

Gravel-filled bags are low-cost, fast and easy to build, require no cement (a major expense and cause of global climate change) and require no forms or expensive equipment. The interlocked barbed wire and poly bags are stronger than a rubble trench alone. It appears that solid weave poly bags kept out of sunlight can last hundreds of years, so gravel-filled bags should last at least a lifetime, while aggregates like gravel or scoria are best for foundations because moisture will easily drain off and won't be wicked up into the wall.

REASONS TO USE GRAVEL BAGS INCLUDE:

1. <u>Good 'boots' for a natural wall</u>: A gravel bag wall can raise a wall system above the soil level outside and the inside floor level. If raised 12”-24” above outside grade (30- 60 cm) a 'raw' earthbag wall (without stabilizer) or a straw bale wall stacked on top of gravel bags will not be hurt by water leaks inside or rain or snow outside.
2. <u>A flood-resistant base</u>: Gravel-filled earthbags starting below grade and extending well above grade in flood-prone areas reduce the risk of being undermined. A rubble trench could get scoured away or soil-filled bags could dissolve and slump in a flood, but angular gravel or gravel with sand is stable even when soaked.

3. Scoria bags are insulated walls: in warm regions they will not overheat in direct sun.

4. Scoria is good insulation in cold regions: Earthbags can also be filled with scoria (lightweight volcanic rock) in cold climates for a simple frost-protected foundation without rigid insulation or deep excavation. Frost-protected foundations are well proven, accepted by building codes and can save thousands of dollars in construction costs.

Earthbags can also be used for a foundation wall faced with stone veneer to provide a naturally water-resistant base of great beauty. See the *Earthbag Design Guide* for more information.

Some prefer to use stabilized soil in earthbag foundations, seeing it as a longer lasting solution. Lime-stabilized bags may be less likely than cement stabilized bags to wick moisture into the wall. Cement attracts moisture and can cause barbed wire to rust or plaster to fail.

If stabilized soil earthbags are used for a foundation wall, they must have drainage, especially in rainy climates and heavy clay soils. A French drain is a slightly sloping underground strip of gravel. A footing drain is a trench next to the base of a footing, with a perforated pipe, often 4” diameter. The pipe in the trench gathers water and carries it to where it can come out of the ground or to a ‘dry well’. Filter fabric around any of these gravel beds prevents clogging in the future.

Gravel Bag or Urbanite?

Urbanite is old concrete debris. Flatwork slabs such as sidewalks and driveways work the best and can be recycled and stacked like stone. Most builders lay urbanite horizontally, while others strive to create a stone-like appearance by altering the orientation. Carefully built urbanite foundations in frost-free, non-hazardous areas may not require mortar.

5-1: Level stacked urbanite
Photo: Dkruidenier

Urbanite is not as quickly built as earthbags filled with gravel or scoria on a rubble trench, but it saves material and energy by recycling a common waste material. Demolition companies and concrete contractors can deliver waste truckloads of urbanite, sometimes even for free. In non-hazardous regions, use urbanite at levels where moisture can cause problems, and set earthbags on top of a vapor barrier.

5-2: A vertically stacked urbanite wall
Photo: D. Acres

Urbanite is not used in bags because rough edges can tear poly fabric. Crushed rubble can be used in bags. New systems with poly-erosion-control fabrics or mesh can contain rubble for foundations and lower walls.

Step-by-Step Directions

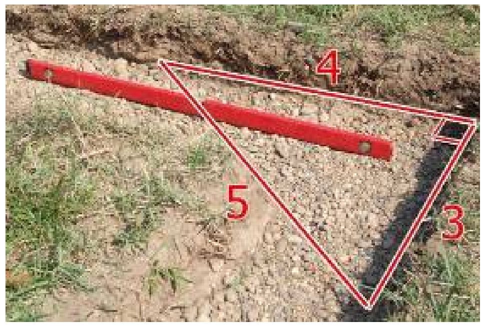
To illustrate just how easy earthbag building can be this section begins a photo series on each main step of construction for building vertical earthbag walls. Each step lists the YouTube "Naturalhouses" channel video. The introduction is *Step-by-Step Earthbag Building: Introduction*.

STAKING

Before building, prepare and slope the site so rainwater drains away. Save time and money by preventing water problems before they start. Make a level space clear of rocks and other obstacles with enough space to work and pile materials. Store topsoil out of the way. Now you're ready to stake out the building with batter-boards. A book on general carpentry shows how to do this. For roundhouses, use a center stake and trace a circle in the earth using a length of twine, then check your layout for level. Make sure to stake out and dig trenches for your foundation and plumbing.

F1 USE 3-4-5 TO SQUARE CORNERS

Measure 6 feet along one side of the building (or 3 m) and mark with a stake
From the same corner measure 8 feet in another direction (or 4 m) and mark
A square corner will measure 10 feet between marks (5 m)

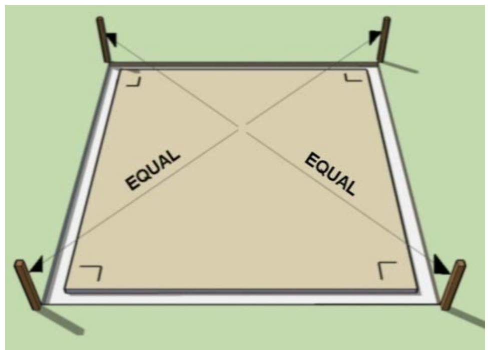


A squared corner is 90 degrees. Squaring corners of a building correctly is a very important step that needs to be done accurately. This method, based on the Pythagorean Theorem, has been used for centuries. Either metric or English units can be used, in any multiples of 3, 4 and 5. The larger your triangle, the more accurate this method is. Measure out 9, 12, and 15 units to square a large building.

Video: ***How to Make Square Corners***

F2 SQUARE THE BUILDING

Square one corner and measure one side
Square each corner and measure the side
Measure both diagonals



If these two diagonals are the same length, and you measured the sides correctly, your building is squared correctly. Always check and recheck your measurements.

This example is for a rectangular building. If you have a more complex shape, measure a part of the layout that is rectangular. A general carpentry book has more details.

Planning For Utilities

Ask local builders how big and how deep the lines must be for the utilities you need:

Buried utilities:	Water supply, greywater drains, blackwater drains
Overhead or buried utilities:	Electric power, telephone, cable/ Internet

Many utilities are buried and must enter a house through or under the foundation, so plan for them carefully. Most earthbag plumbing issues are the same as in houses made with other materials. Check out a plumbing book from your library and you'll be able to do a simple house. Plumbing is not terribly complicated; it just takes careful planning and some time. Plumbing your earthbag home can be divided into two steps: rough plumbing and finish plumbing.

F3 Dig Footings

Dig a trench slightly wider than the earthbag wall and about 18"-24" deep
Add gravel, rock or urbanite until level about 6" below finished grade
Tamp rubble trench until solid and level

Build rubble trenches for any buttresses at the same time.

One course of bags should be below grade. This keys the wall into the earth, making it stronger. Some people have built earthbag walls on grade on a rubble trench without keying into the earth and have not experienced any problems so far. Have at least one or two courses set below grade for best stability.

In sandy soil a layer of mesh can hold the trench walls in place until the fill is complete. In heavy or damp soil, provide a French drain or pipe to allow the footing to drain after a heavy rain.

A footing trench should always reach undisturbed subsoil. Building a heavy earthbag wall on top of soft, disturbed soil or fill can make a wall settle, sometimes unevenly.

A drainage trench for a stepped footing

On a sloping or rocky site in non-hazardous areas the footing trench may be lower on one side to reach undisturbed ground. Fill the trench with stones and gravel to create level steps so that your gravel bags will be level and stable.

A building foundation on sloping rock may need holes drilled in the rock. Inset rebar pins so that the weight on the footing will not make the wall slide towards the low side.

Video: [***Foundation Height***]()

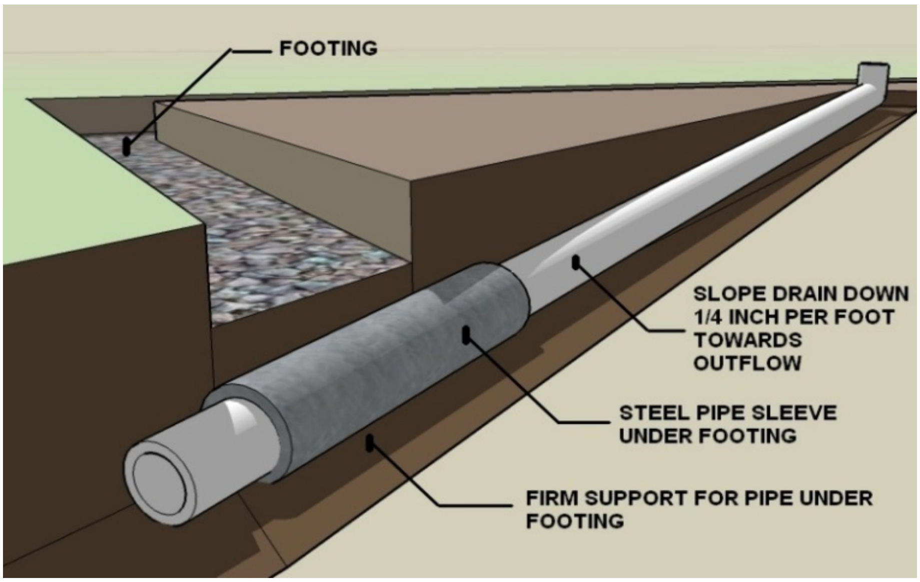
Short gravel bag courses form a base on level, stepped footings

F4 INSTALL ROUGH PLUMBING

Stake out utilities while you stake the rest of the house
Dig trenches below the frost line for plumbing
Run utility pipes

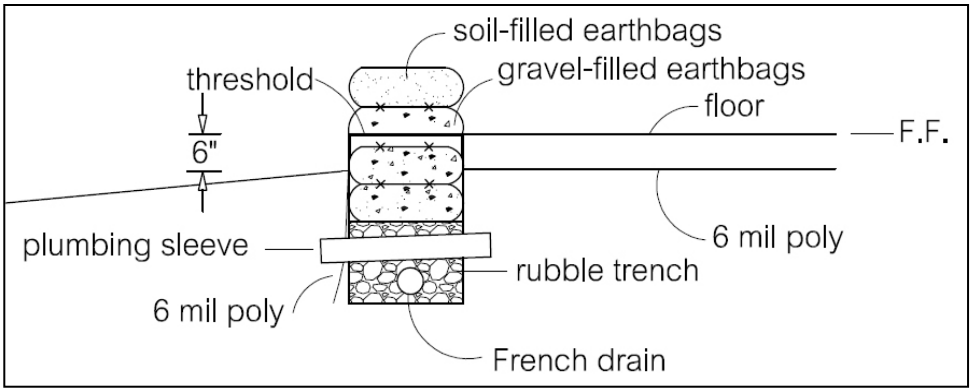
Always try to run water lines below the footings. Plumbing should not be run through unstabilized earthbag walls, where water leaks could cause serious structural damage. Use cement with the bag fill near a plumbing line and/or a plumbing sleeve where pipes have to pass through a wall.

Sink, shower and toilet drain lines need different depths below the floor for the curved traps that keep septic gases out of the house. Most building codes require an inspection before backfilling. If not, ask a plumber friend to check it for you. Make sure to have everything hooked up correctly before burying.



F5 Add Pipe Sleeves

Put a strong metal sleeve in an earthbag wall for a pipe or electric line
Tilt it down toward the outside for drainage
Mark its location with a stake
Mark the location on a drawing to save



Get 24” lengths (60 cm) of galvanized or stainless pipe at a scrap metal yard. Don’t buy rusted pipe or thin-walled pipe for this because earthbag walls are very heavy and could crush your plumbing. Use a large enough diameter pipe so you have a little extra space to work with. After the plumbing is done, seal the gap between the plumbing and sleeve to keep water and pests out.

A couple extra pipe sleeves on each side of the building in walls and footings may come in handy sometime in the future. These almost-free items can be very valuable for extra plumbing, wiring, or even for drainage from an unlikely flood.

F6 Fill Gravel Bags

Use doubled solid weave poly bags for gravel
Use the same number of buckets of fill for each bag
Fill gravel bags in place

Angular gravel interlocks well for strong walls. Bags filled with round gravel will also work, as long as the gravel sits well and doesn’t slip.

Fill bags about 90% full, leaving just enough room to close the bags. They will look fat but tamp them down a little. A bag filled to capacity saves bags and keeps each bag the same size so walls stay level. ‘Thin bags’ not filled all the way wastes bags, creates more courses

and uses much more barbed wire and labor. One way to be sure that you use the right amount of fill is to line up the right amount of buckets before you start on each new bag.

Note: If your foundation wall uses stabilized soil, check the directions on pages 31- 33 about pre-tamping and tamping for filling and placing earthbags. Soil mix for stabilizer must be well mixed before cement or lime is added. Soil with Portland cement must be placed within 20 minutes of adding cement and moistening.

Video: ***Use the Same Number of Buckets***

F7 Place Gravel-Filled Bags

Work from the corners of walls or openings towards the center
Tilt bag down against previous bag

It's best to double-bag the gravel for added strength. Place bags on a level gravel bed 6" lower than the finished soil level. The gravel and/ or rubble bed should be at least 12" deep and tamped solid.

If rebar pins were used on a concrete footing, lower bags straight down onto them.

Video: ***Double Bags***, ***1st Foundation Bag***, ***2nd***, ***3rd***, ***4th***, ***5th Foundation Bag***

F8 Check Alignment

Align bags to a string-line.

For rectangular buildings tie taught strings between corner stakes or batter boards. Look down from directly above the string to see that the bags all line up. Stand several feet away in line with the wall and eye the wall for bulging bag corners or any bags that aren't lined up properly.

For round buildings check each bag against a measuring string from a central post.

F9 Keep Bags Full, Close, and Level

Place a whole course, fitting bags snug to each other
Tamp the bags to settle and level, first the center of a bag, then the edges

Always butt the tops of bags (the ends you've closed) against other bags. Tilt the tops down against another bag, but never face the tops outward on corners or wall ends.

Sometimes it is best to lean the new bag on the old and lift the end of the old bag slightly to let the new bag settle down. The second and the last bag on a course may need this extra care.

Tamp the bags flat after each course is complete, but remember that excessive tamping tears bags. Gravel-filled bags do not need much tamping.

Because gravel bags cannot be tamped to form thinner courses, it is important to keep the same amount of gravel in each and start on a very level foundation. If the wall becomes not perfectly level after a course or two, use a little less gravel in the next course bags on the higher spots. It is much easier to adjust levels on courses with earth fill by adjusting the amount of fill when pre-tamping and by extra tamping.

Video: ***Tilting Bags Together***, ***Tamping Foundation Bags***, ***Check Level***

F10 Add Barbed Wire

Untwist and straighten barbed wire as you pull it off the reel
Lay two strands of 4-point barbed wire on top of each course of bags.

Use bricks or stones to temporarily hold the barbed wire in place. (On higher walls, it may be safer to pin the wire with nails or staples so that nothing can fall off onto workers below.)

Run continuous barbed wire around corners for high wall strength.

Video: ***Barbed Wire***, ***Cutting Barbed Wire***

Safety warning:

Working with barbed wire is dangerous. Use thick leather gloves and stay alert. Keep others away from barbed wire work. Barbed wire tends to recoil (spring loose) and can cause injury.

F11 Use the Slider under Bags

Place bag on the slider so the joint will be offset from the course below
Close top tightly
Tilt bag down against previous bag

Starting on the second course, the slider will keep bags from getting hooked on the barbed wire. Place the bag where the bottom will be near the end of the slider so pulling it out is easier. Lift the end of the bag a little and give the slider a little jerk.

Adjust bags so that after tamping them the edges will be directly above the course below. This will keep walls vertical.

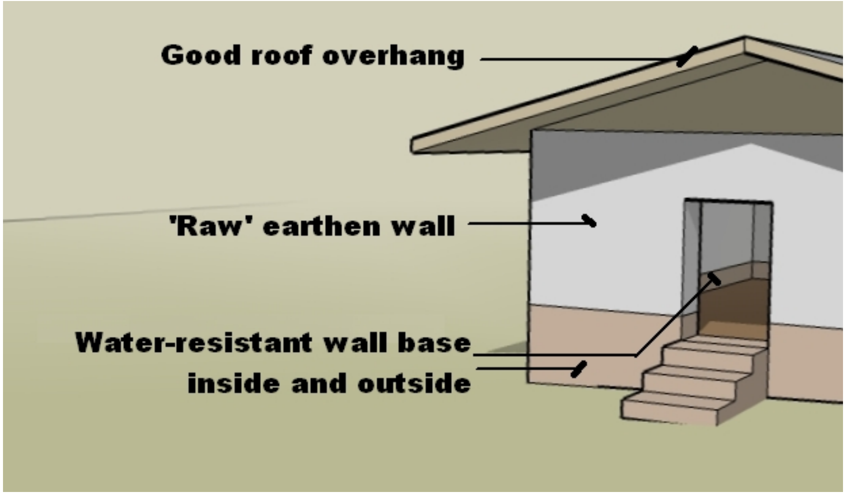
Strong workers may want to pick up bags to adjust them. Because full earth and gravel bags can weigh much more than 100 pounds, wise (or weaker) people save energy and prevent back injuries by twitching bags on the slider or rocking them from side to side to adjust their location.

Instead of small buckets you might also use a 4 or 5 gallon bucket chute (15-19 liters) in the bag to measure soil added with shovels. Scrunch the chute all the way down to the bottom of the bag, fill to the top of the chute, then pull the bag and chute up and fill to the top again.

Some builders measure from the bag top and draw a fill line inside each bag that workers fill to. Find a system that works for your crew.

F12 Water-resistant Bags Above Floor Level

Use gravel-filled bags until 6" above the risk of moisture damage



In rainy climates, especially those with strong freeze/thaw cycles, extra height is needed to protect earth walls. Water-resistant bag courses should extend higher than the deepest snow.

If your building has plumbing, it is wise to lay water-resistant bags to 6" above floor level in case of accidental leaks. Where gravel is expensive, stabilized earth or a mixture of gravel and sand could be used as bag fill instead of pure gravel.

A layer of 6 mil polyethylene sheeting can also be added around the outside of these lower courses to keep water away from the foundation.

F13 Subfloor

Fill to 6 inches below finished floor (15 cm)

When the foundation wall and rough plumbing are complete, place any planned insulation. Rigid board insulation is best for possibly damp conditions, but light gravel like scoria works well in a dry location. Keep scoria clean with a layer of filter fabric, then add a base layer of fill inside the building to make work easier. See pages 80-82 for more information on floor construction.

Use only clean fill without any organic matter. Concrete rubble can be used if it fits beneath the subfloor level. Rake subfloor smooth and level and tamp lightly.

Chapter 6 – Bag Walls

Basic Wall Techniques

Each step lists the relevant YouTube Naturalhouses channel instructional video. The introduction is *Step-by-Step Earthbag Building: Introduction*.

W1 Fill Earthbags with Soil

Turn bags inside out before filling
Use the same number of buckets of lightly moistened soil
Pre-tamp the contents slightly after each bucket is added

Earthbags take a little more care than gravel bags. After each added bucket, use a small tamper inside or outside the bag or press the bag with your knee. These fat bags will be filled to capacity, saving bags, barbed wire and labor. Equal-sized bags also keep walls level with less work.

Turning bags inside-out is my preferred technique to prevent corners of bags sticking out and interfering with the plaster. Simply turn the bag inside-out, so it has a smooth edge, like the photo below on the left. This can give better bonding for plaster and will prevent lumpy corners. Don't poke the corners out all the way, or it will end up with bulges at the corners like the bag below labeled 'Inside-out'.

Some builders tuck the corners in (diddle them) or pin them to make them neat so walls are flat and smooth. This may be more critical with loose or sandy bag fills. Tuck your fingers inside up to your second or third knuckle, or pull the corners in from inside the bag.

Video: ***Use the Same Number of Buckets***, ***Turning Bags***, ***First Earth Filled Bag***, ***Tamping First Earth Filled Bag***

Labeled photo: P. Stouter

W2 Close the Bags

Fold the bag end over
Close the end with wire, thread, or a tag

Closing bags securely prevents spills and enables bags to be filled to capacity. Bags can be moved and adjusted to get their location just right without spilling or re-closing.

In many places stitching with wire is a low-cost, moderately quick technique. Use 16 gauge wire about 9” (22 cm) long with one end cut at a sharp angle. Make one stitch on one side and bend the end over; make a stitch in the center and pull the corner over; make a stitch in the other corner and pull the corner over; poke the remaining wire into the earthbag.

Some people use several nails to close each bag of a dense, clayey soil. It is less effective in light, sandy soils. Others prefer to sew the bags closed. This is inexpensive and can be done by weaker people, but takes time.

You can also staple the bags closed with a heavy duty stapler, or a less expensive alternative is to buy a tool used to attach price tags to clothing. A tag attacher has a sharp needle end with a cover, is cheaper than a good stapler, and works quickly. Use three 1/2” (12 mm) plastic tags on each bag top. It can also be used to tack diddles in place. Follow safety instructions, and use different replacement needles for different workers.

A small tag attacher; photo: P. Stouter

Some people use partially filled bags and tuck the end under the bag, because it takes less time than closing bags. The 30” long standard bags measured when empty (76 cm) are about 20” long (50 cm) when folded and overlap only about 5” (12 cm). A 5” overlap may not be enough. An 8 or 9” overlap makes a strong running bond. See more information about overlap in the next section.

Videos: ***Stitching Bags Closed***, ***Sewing Bags Closed***, ***Pinning Corners of Bags with One Stitch***

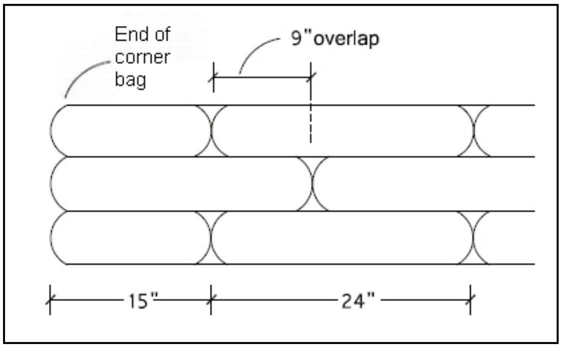
W3 Place The First Course

Work from wall corners and openings to the center
If rebar pins were used, lower bags straight down onto them
Place bags so joints from course below are offset in a running bond
Tilt each new bag down against a previous one

Because gravel prevents moisture from wicking up into upper courses, no other moisture barrier is needed. Place earthbags on gravel bags that extend at least 6” above the floor and above flooding, snow or rain splash levels. On a concrete footing place earthbags on a plastic moisture barrier. On lime- or cement-stabilized bags or a footing with rebar pins, add a layer of tar below ‘raw’ earthbags.

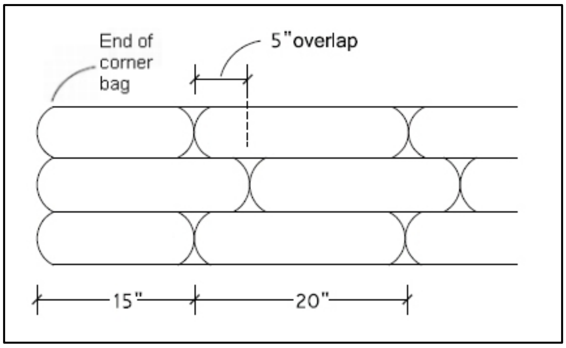
Always butt the tops of bags (the ends you’ve sewn closed) against other bags. Never face the weaker tops outward on corners or wall ends. Face firmly pre-tamped, strong sewn bottoms out. Align bags to the string-line. Straight and plumb (vertical) will be strong and easy to plaster.

Maintain a running bond as done in masonry. The joints between bags should never line up between courses. It adds strength to walls when upper bags hold lower bags in place well. In a rectangular building, the location that starts the bond pattern is the corner where every other course has a bag end.



Good overlap with 24” long bags

Longer bags are easier to overlap well. 30” long bags (76 cm) measured when empty make a 22- 24” long (56- 60 cm) building unit when full and firmly fastened. This is a convenient size module to work with and allows an 8”- 9” bag overlap (23 cm) between courses for strong walls.



Poor overlap with 20” long bags

Longer bags are heavier and more difficult to work with, but require fewer bags per building, and take less time. In seismic areas or other situations where extra strength and overlap is required, long bags are important. The top diagram shows how longer bags can provide a better overlap without requiring extra custom bags. Other ways to deal with this issue are covered in more detail in the *Earthbag Design Guide*.

Video: ***Tilting Bags Together***, ***Overlap Bags***, ***Protruding Corners***

W4 Make Custom Bags

Measure the opening
Fill the bag to the approximate level
Fold the end under
Place the bag in the wall

It is best to lay bags starting at the corners and doorways and work toward the center of the wall. When you get to the center, you'll probably have some small spaces left. Make a custom bag as shown for this purpose. The soil will compress quite a bit, so use extra fill. Trim the bag fabric and fasten closed, or just tuck it under tightly.
Place small bags offset from ones in the course below to keep a good running bond overlap.

Video: ***Custom Bags***

W5 Tamp the Course

Check walls for level every course or two
Tamp the high points first
Evenly tamp the entire wall several times as you continually move the tamper

Tamp earthbags solid and level after each course is complete. Check the wall for level every few courses. On long walls, a hand held level will not work. Raise strings with line levels or use a water level to mark the level on corner guides.

Slight level errors can add up. If tops of walls end up 6 inches off (15 cm) from one corner to another it will either require a lot of extra cement for a thickening bond beam, or result in a sloppy looking roof that may be less safe in hazardous areas.

Tamping the high points first prevents creating low spots. When tamping, let go of the tamper just before it hits the bags or the jolting force will go up into your arms.

Heavy clay soils compress more when tamped than other soils. Moderate tamping may be fine, but well-tamped walls have extra strength.

Video: ***Tamping First Course of Earth-filled Bags***

W6 Lay Barbed Wire

Lay two strands of barbed wire on each course
Barbed wire must be long enough to reach around the building

Use four-point barbed wire and run it around corners for strength. Many earthbag builders prefer to uncoil barbed wire directly on the wall. This is easiest with small rolls of barbed wire. This eliminates measuring and makes it easy to remove the twist (by straightening a little at a time as you go) so the wire stays in place against the earthbags.

Because barbed wire rolls are heavy, some prefer to pre-cut it to the right length. Measure the first piece, mark the distance on the ground with a stake, and then cut all the other pieces the same length.

Video: ***Barbed Wire***, ***Cutting Barbed Wire***

Safety warning:

Be careful handling barbed wire. It is springy, and can bounce and grab or scratch bystanders. Keep extra people out of the way when handling longer pieces.

For building strength:

Barbed wire should not end at corners. If it must end, overlap the new strand by at least 24" (60 cm), and do it in the center of a wall.

Straight or Zigzag Barbed Wire?

Lay barbed wire straight. The recommended practice is to place barbed wire in concentric rings on domes and roundhouses and in straight, parallel lines on rectilinear designs.

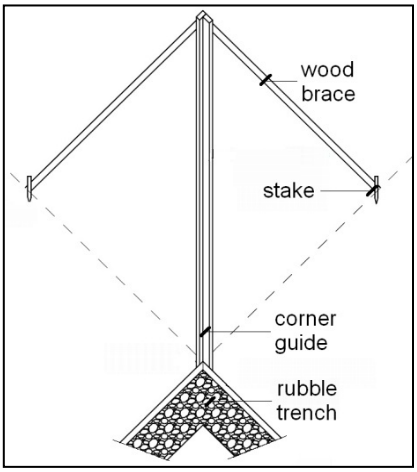
Zigzagging the barbed wire provides more attachment points, but reduces wall strength. A load like a hurricane, earthquake or differential settling would tend to pull the bags and structure apart as the slack is taken out of the wire.

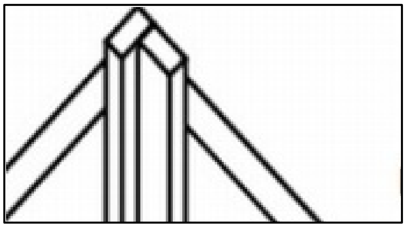
A 10’ long, 8’ high earthbag wall can weigh more than 10,000 pounds. The eighteen strands of straight barbed wire embedded in it (two per course) can support 18,000 pounds. Straight wire will do its work well.

W7 Build Corner Guides

Brace in a vertical position

Corner guides make it much easier to keep walls vertical as you build. Use two 2x4s nailed at right angles.





Be sure to check for plumb in both directions on the guide. Pipe or rebar can be used if wood is not available.
Video: ***Corner Guides***

W8 Place Bags on Barbed Wire

Tilt the bag into position and align it
Hold the end of the bag to jerk the slider out

The sheet-metal slider keeps bags from snagging on the barbed wire and makes it easier to line them up carefully. It helps to lift the bag end slightly to remove the slider. If bags are lined up very straight and vertical above each other, plastering is much easier and takes less material.
Video: ***2nd Course of Foundation***, ***Tamp and Level Each Course***

W9 ADD TIES

Lay a tie across each bag every fourth course

In many cases ties are not needed. But if necessary, use strong cord, wire or strapping 24”- 28” long (60- 70 cm). Place the ties in the wall while the courses are laid.

Ties to earthbag walls are needed for many different purposes.

In low risk areas sturdy strapping around 3 or 4 courses of bags can be used instead of rebar to hold walls together vertically. Sometimes ties are needed to attach electrical wiring or help hold plumbing lines in place. In high risk areas ties attach the mesh layer that forms a reinforced structural skin with plaster or stucco. These ties should be tied to the barbed wire to add strength.

W10 Vertical Rebar Reinforcement

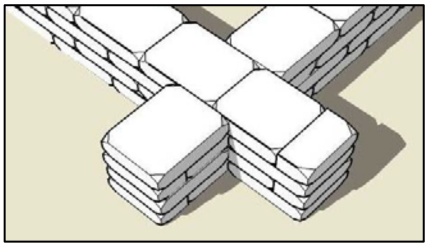
Hammer rebar in near corners and openings

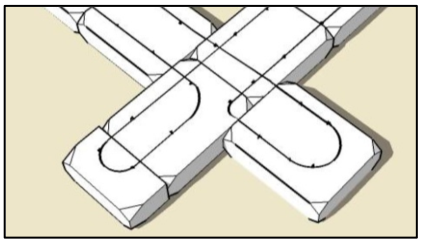
It takes less work to hammer rebar into walls than to build buttresses at all corners. Rebar 12" from ends of walls and openings (30 cm) adds strength. Hammer 4' long rebar (1.2 m) in at 4' and 7' heights (1.2 m and 2.1m) so it will overlap within the wall.

In high risk areas use vertical rebar more frequently to add strength. See *Earthbag Design Guide* and/ or ask an engineer about reinforcement spacing.

W11 Buttresses or Piers

Build buttresses at least one full bag length
Tie buttresses into walls with bag overlaps
Lay barbed wire continuous
Thicken walls to create piers at openings





Traditional adobe uses short bracing walls to reinforce vulnerable corners and openings. If rebar is not available, buttresses at corners will ensure their strength. Straight walls should have an intersecting wall or a buttress or pier every 12- 16' (3.6- 5 m).

Buttresses can slope or step in to the building wall at the top. The bracing action at the bottom and lowest 6' (1.5 m) of the wall is the most important.

W12 Flatten Walls to Reduce Plastering

Tamp the sides of the bags to flatten walls

Tamp the sides of courses with a tamper or mallet, to save a considerable amount of time, labor, and materials during the plaster work. Walls are always slightly irregular even if you are

careful, so find obvious bulges. Corners and edges of openings where sharp bag corners stick up beyond the general wall surface are first on the list. Don't flatten the wall entirely, because the recesses between courses give the plaster something to grab.

Have several courses in place before tamping the sides, so you can easily see where the high spots are. But don't wait too long, or the soil will be too dry to compact properly. It should compress and not crumble when hit. Once walls have started drying, it may not be possible to moisten and re-soften portions. It is difficult or impossible to get water to soak in instead of running down the wall.

The neater your wall is, the easier the plastering will be. If you will use an earthen or lime plaster inside and a more expensive cement stucco outside, keep the outer wall smoother than the inner wall. Earthen or lime plaster can have a less expensive earthen base coat to level a bumpy wall.

Video: ***Smashing Protruding Corners***

W13 Protect Fabric from Sunlight

Spray or paint bag walls with latex paint or whitewash
Keep walls covered or use UV resistant fabric on longer jobs

Polypropylene and HDPE bags and tubes are susceptible to ultraviolet (UV) damage if left exposed to sunlight for more than a few weeks. High intensity sunlight in deserts, near the equator, and at high altitudes is the most damaging. In temperate regions and low altitudes bags may only be damaged after several months. UV damage cannot be reversed.

Plaster sprayer; photo: N. Scheid

Although a good bag fill containing clay may hold up the building with or without the bags, in high seismic risk areas bag strength is important to help walls resist stresses from horizontal shaking.

Tarps can protect the walls during construction, but tarps blow in the wind, take lots of time covering and uncovering walls, and cost a fair amount of money. For large jobs order UV-resistant bags and tubes, use a broom to cover bags with cheap paint, or spray on a thin sandy plaster layer.

Any cracked plaster layers should be removed or well-soaked before the final earth or lime plaster is applied. In some cases tamping of upper walls may shatter plaster applied early to lower walls, and loose plaster can weaken the final coat. Because cement stucco does not adhere well in thin coats, is more brittle and does not expand and contract as much as earth or lime plaster, cement stucco finish may not work well over thin earth or lime plaster layers.

CHAPTER 7 – Tube Walls

Dome builders have been using tubes to build for many years, but vertical walls can benefit from tubes as well, to speed work and reduce plastering needed to fill nooks between courses and bag ends.

The photos and instructions in this section relate mostly to building Hyperadobe, or walls with raschel mesh tubes. This information and these photographs (unless noted otherwise) have been graciously supplied by Fernando Pacheco of EcoOca in Brazil. Because the mesh tubes are easy to load on a chute and cost significantly less than solid weave poly bags or tubes, mesh for building will likely become one of the preferred techniques.

Video: ***Hyperadobe***, ***More Hyperadobe Videos***

Building with solid weave poly tubes (like Cal-Earth's Superadobe technique) is similar but requires more effort to load the shorter sections onto a chute. With solid weave tubes you must also use a slow twist of the tube to keep a curving wall aligned correctly.

Mesh material, made of knit HDPE fabric, must be used with soil fill that contains enough clay. Since the bags are weaker than solid woven bags they are most appropriate in non-hazardous locations. For those locations mesh tubes make walls quickly and efficiently for teams containing 3 or more people. The greatest time saver is the fact that all those bag tops don't need to be separately closed and can't stick out. Even the ends of mesh tubes can be made fairly smooth with a little care. And plastering mesh walls is quicker both because the wall dries quickly and because plaster adheres easily to mesh.

Because the raschel fabric is not slippery like solid poly fabric, barbed wire is not necessary as a mortar between layers. One course will sit securely on the course below. On larger and straighter-walled buildings, one or two strands of barbed wire might increase wall strength even if not needed for stability during construction. Barbed wire might be helpful at corners and over openings.

T1 LOAD THE CHUTE

Slide as much tubing as possible onto the chute

Use tubes that form walls 14"- 15" wide (36- 38 cm). This will be mesh that can be stretched or lays flat at 18"- 19" wide. Mesh tubing should fit

snugly on the bucket chute. Solid weave polypropylene tubing may be slightly looser on a chute. The chute can be made from metal or plastic, with duct tape or epoxy covering pop rivets or bolts that stick out to protect the mesh. Some builders prefer having two chutes to keep an extra pre-loaded.

See if you need a shoulder strap. If the tube is inserted up through the inside of the chute and pulled down over the outside of the chute, it is easier to control the rate at which it feeds out. But a shoulder strap is difficult to use when fastened to the bottom of the chute, so some builders don't use straps.

It is easiest to load mesh on a chute if the mesh roll is held or placed above the chute. A simple trick is to place the roll of mesh on a pipe that is fastened to a door buck at about shoulder height. Load as much tubing at one time as possible, to reduce breaks in the wall and keep workers moving ahead.

T2 START A COURSE

Tie a firm knot near the end of the tubing
Stand facing the opening or corner
Hold the knot under your foot
Step backward along the wall as helpers pour fill into the chute

When laying tubes on the wall keep the chute near chest height. Start with the knot facing away from the beginning of the wall. Pourers bring buckets of fill and pour them into the chute. Fill the tube back over the knot. Then begin to back away from the opening. Overfill the tube at first to allow a firm edge, and pre-tamp it. Shake the fill with your foot to help it settle firmly. A placer can adjust the tube to lie directly above the course below.

Keep twisted mesh ends tucked under;

Top photo of untamped mesh test: P. Stouter

Some fine soil may fall through the mesh. Keep the soil fill just moist enough that only a thin layer of fine soil falls through the tube. This may be slightly moister than usual for solid weave bags or tubes. Sandy soils that might work in solid weave tubes or bags might need a little more clay to use in mesh tubes.

T3 KEEP THE COURSE EVEN

Keep the tube curving upward
Step back a little for a little fill

Even stretchy mesh tamps to surprisingly uniform widths. Adjust the size of steps backward relative to the fill applied. Keep a gentle curve in the tube. The tube will be fullest if it curves up to

as near vertical as possible. If the filling has obvious cracks, keep the mesh in a gentler curve.
The chute loader controls the thickness of each course and should try to keep the wall level or correct for slight changes. It is probably easier to over-fill or under-fill separate bags than tubes to adjust for level changes. So it is important for the chute loader to keep the tube fill uniform. This may be the job for a more experienced worker.

Corners of solid weave tubes;
Photo: J. Kennedy

Some builders may want to use a bag at each opening edge, so that the strong seam edge can be pre-tamped extra firmly to avoid drooping. This may be more important with solid weave tubes than with mesh tubes but since mesh seems to make courses slightly thinner than solid weave tubes or bags, and barbed wire is needed between solid weave bags, mesh bags may work best with mesh tubes.

T4 NEAT OPENINGS

Shake the tube to fill it full
Always tamp from the middle of a wall outward

Be careful to add generous amounts of fill at the beginning and end. Just as bags should be filled fat, aim for a fat tube at the beginning and end of a wall section, or at a corner.

Tamping from the middle of a tube wall towards the ends does move soil towards the ends and keeps them firm and level.

Photo below: J. Kennedy

T5 FINISH A COURSE

A helper twists and cuts the tube
Shake the tube back to settle the soil
Tuck the end underneath
Fine-tune placement

Although there are few breaks in tube walls, make sure they don't occur at the same place in a wall. Alternate which walls extend through at wall intersections to tie them together well.

Tamp the walls and the sides as needed to reduce need for plastering. Plastic bags on tampers may help reduce sticking to the earth fill that is exposed between the mesh fabrics.

Lay ties or strapping on courses as needed. If no barbed wire is used, ties to hold electrical wire or protective plaster mesh for more vulnerable locations can be knotted and stapled into a course. Ties can also be used in longer lengths that extend under and over a course.

Vertical rebar reinforcements are a good idea at corners and near all openings. Although the earth of upper courses attaches to the earth of lower courses through the mesh, rebar can add valuable tensile strength. Earth is very strong in compression, and can hold great weight up, but it has low tensile strength and the open mesh interrupting it between courses will still allow the courses to separate under twisting or sideways pressure.

If horizontal reinforcement is desired, it is possible to use wire mesh or geo-grid that can be pierced by the vertical rebar. This type of interconnected reinforcement grid has been proven most effective at preventing earthquake damage to adobe buildings. Testing is needed to explore the strength of this type of reinforcement in mesh walls.

Follow directions on pages 41- 42 for reinforcement and buttressing, and unless your tube is UV protected, protect it from damage by sunlight.

Chapter 8 – Openings and Details

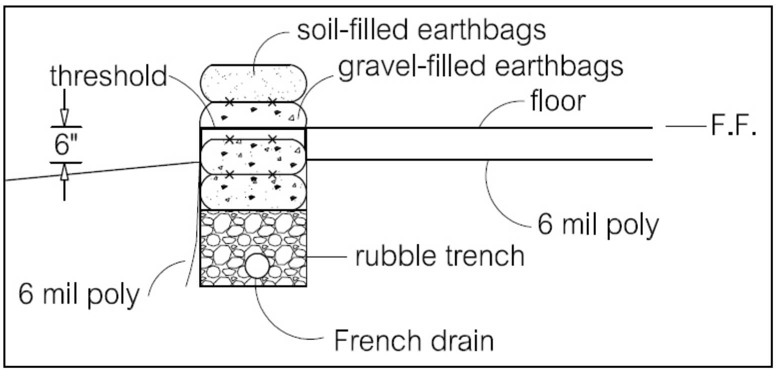
Locating Door or Window Openings

Remember, openings in earthbag walls can reduce strength. Openings should be 36” (90 cm) minimum distance from openings and corners. Bracing walls perpendicular to long building walls should have openings at least 5’ from the supported wall. The *Earthbag Design Guide* has a full discussion of spacing.

Also, refer to a general carpentry book for proper techniques on window and door detailing to make sure you don’t have moisture problems. Use galvanized metal flashing above doors and windows to lead moisture away, and build waterproof sills for windows that slope outward. Wide roof overhangs also help reduce the moisture to which doors and windows are exposed.

01 Make Door Thresholds

Start bag courses 12-13” (30-33 cm) below the finished floor level
Pour concrete sills 2-3” (5-7 cm) thick on top of the earthbags at doors
Finish the concrete surface neatly



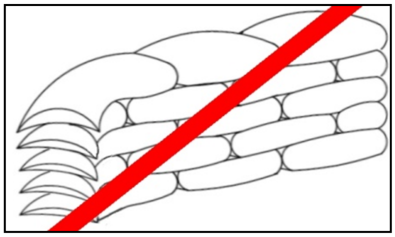
Allow enough drying time before building the door buck. Use at least two continuous courses of earthbags below the threshold set on a rubble trench for strength. The continuous barbed wire will give strength to tie the lower walls together.

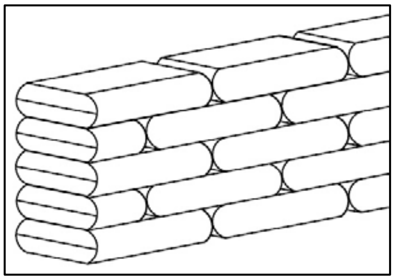
Finished floor height (F.F.) in this case is the same height as the threshold. You can pitch the threshold down to the outside to drain, and add concrete pigment to make it any color you want.

Slate or tile or natural stone can be used for thresholds instead of concrete, but natural stone will be thicker and could require changes to the levels of the earthbag courses. Decide on the type of finish before starting to build your footing.

O2 PREVENT CORNER DROOP

Pre-tamp the soil in corner bags carefully while filling
Tamp lightly next to openings and at wall corners





Use extra tamping when filling bags for corners or next to openings. Some earthbag builders have problems with drooping (slumping) earthbags at corners and next to window and door openings. Bags in the center of walls are butted against other bags and supported by them.

Unsupported bag ends near openings or corners tend to slump. Pre-tamp every bag, but tamp extra on corner bags and end bags. Densely compacted bags won't slump like the upper drawing, but stay level and form a firm edge at the opening, as shown in the lower drawing. Wall corners will stay level if carefully pre-tamped.

Tubes cannot be as fully pre-tamped, but can have extra fill shaken in and compacted in between additions. Pre-tamp it through the tube with a board, brick or mallet and by twisting the fabric tight. Always tamp tube courses from the wall center towards the openings, and remember not to tamp the corners and ends too much, in order to keep each course level.

O 3 INSTALL DOOR BUCKS

Set the door buck(s) or rough frames in place where doors will go
Set them plumb and level and brace in position
Pin sides of the frames with rebar pins into the bags

Bucks are rough frames to keep earthbag openings straight and the right size for your door openings. They are especially helpful for doors because it is hard to keep an unprotected opening perfectly straight and vertical as the wall gets higher. To make a very neat earthbag door opening, the door buck should be almost as wide as the wall. Build anchors into the wall every fourth course. If bucks will remain as door frames, screw the anchors to the bucks as you install them.

For places where wood is susceptible to termite damage, install a metal door frame early to function as a door buck. Or build a partial wood buck that can be raised on blocks or lightly tamped earthbags to keep it at the level of

tamping. Some builders use a buck of narrower wood that can be easily removed and re-used for rafter construction. You can also save money by using long poles for the braces to keep bucks vertical instead of milled lumber.

USING SMALLER LUMBER

Many natural builders build door and window bucks out of wide lumber – often 2x10s or 2x12s (5x20 cm or 5x30 cm). We use 2x4s instead of wide lumber (5x10 cm) whenever possible to save old growth trees and money. Smaller dimension lumber such as 2x4s can be obtained from smaller trees, which makes this process more sustainable.

For rough window and door frames, put two 2×4 frames (5x10) side-by-side. The finish window and door frames can hide the joint between the two narrow frames. In fact, it's impossible to tell the difference when finished -- the look is the same as wide lumber. So with just a little more time and effort you can save some money and reduce the strain on forests.

04 Place Anchors

Cut sheet metal into 7"x12" rectangles (18 x 30 cm) with tin snips
Score a line about 2" from one end (5 cm) with a large nail and straight edge
Bend the metal along the line into a right angle
Add some nails from the bottom side

These anchors will let you attach window or door frames, shelves or base cabinets to your earth walls. Anchors are added as the earthbag wall is built. For doors and windows they must be about four courses apart. Fasten the hinge side of the door frame most securely.

A 16d nail and a piece of sheet metal work well to score the metal. Score (scratch) the metal about three times and bend it with your hand.

Place the anchor in position and then add nails into the earthbags below

In areas with termites, it's best to use anchors made of galvanized sheet metal. They're inexpensive, strong, easy to make from scrap metal and resistant to decay. Because they're thin, they don't take up space between bags. Galvanized

roofing nails work best to secure the anchor to upper and lower earthbags. Place the anchors on both sides of frames or openings about every four courses of bags. Use screws to fasten the anchors to permanent door or window frames. You can pay a little extra to have the metal pre-cut in a shop.

Wood anchors are similar. Many people in regions with low levels of termite damage and wood decay use wood for anchors. Use a little less fill in the bag to compensate for the wood anchor but keep the wall level. If neither wood nor metal are available, pound 24 inch rebar pins (60 cm) into the bag next to the opening, bend toward the opening, insert end through a hole in the buck, and hammer the end over to hold the buck.

Hold anchor bolts in place with a plate

Place a galvanized or painted metal strap or a plate 6”- 7” long (5 – 18 cm) with 2 holes between the 2 bags nearest to the opening. Insert a galvanized or painted bolt or threaded rod through each end of the metal plate. Use a washer and nut to fasten rods to door, window, or wall frame.

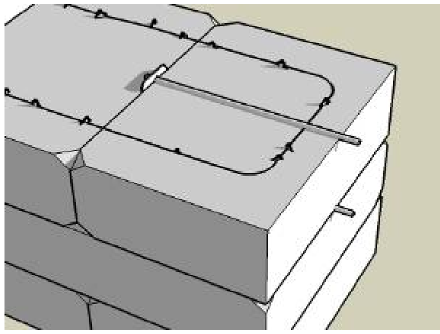


Image: P. Stouter

05 Round Door and Window Edges

Pin bags next to door or window bucks to round edges

Diddle each bag, or pull the bottom corners of each bag to the center and secure with galvanized wire or nails before filling. Pre-tamp bags and fill generously.

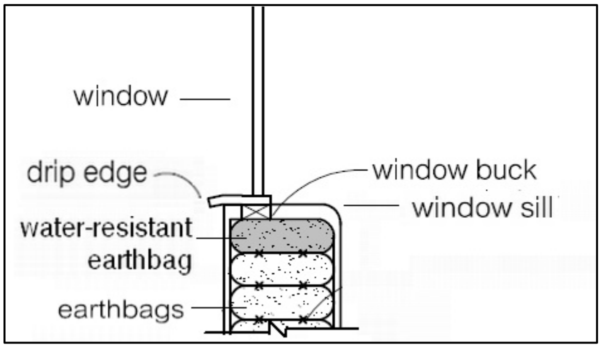
Bag with pinned corner

Rounded edges around windows and doors create beautiful curved openings that enhance views and allow maximum light to enter. Square openings are a little easier to build, but result in ‘tunnel’ openings that look crude in comparison. Rounded openings have numerous advantages. Around doors they add a little extra space, making it easier to pass through. Around windows, they widen and improve the views. And the window surrounds will be simpler to plaster.

Videos: [***Pinning Bags,***]() [***Pinning Corners of Bags with One Stitch***]()

06 PREPARE FOR WINDOW SILLS

Use water-resistant bags below the window sill or a waterproof layer
Pre-tamp top of sill bags to slope slightly outward for drainage



Un-stabilized earth walls can be damaged by water in humid climates. Window sills need extra protection from rain and / or snow. A tile, brick, or stone exterior sill can lead water off the wall to prevent it from soaking in.

Since bags under the sill may be exposed to more dampness than the rest of the wall, a gravel bag or lime stabilized earthbag can be used just below the window sill to resist damage from water. Using materials that absorb less water under window sills is especially important in climates with frost and (in buildings with lime or earthen plasters) to ensure quick drying. Another material that dries out more easily than cement stabilized earth is a layer of fired bricks. To attach smaller units like brick securely without piercing waterproof gasket layers, use metal lathe fastened to the side walls.

07 INSTALL WINDOW BUCKS

Place a waterproof sheet on earthbags at window opening
Set the buck in the correct location and check for plumb, level and square
Brace in position as needed
Pin sides of frame with rebar pins into bags

Window bucks are similar to door bucks. After placing the buck, continue stacking and tamping bags. To prevent the window bucks from moving when adjacent bags are tamped, some builders slide pole braces up as the work rises. When the work is done the side boards can be removed.

Removable window bucks; photos: M. Long

The simplest window bucks are those for round openings. A section of concrete drain pipe, a corrugated metal culvert coupler or a rim for a farm machine wheel can be left in place to serve as a sill. A tire can also serve as a temporary form.

Round window; photo: J. Balmer

08 Transoms

Use space above doors for vents or transoms

Wood transom vents are often window panes that tilt for ventilation. Wood slats can be used for fixed vents, or openings with only window screen if there is a good roof overhang above.

This space simplifies building by using a single bond beam to also function as lintel.

09 Pipe Vents

Inset a pipe section for a small vent

Slope the pipe slightly downward to the outside so that any water blown in will drain out. It must extend past the plaster on the exterior and as far as the plaster on the interior. If a female threaded plastic pipe with a threaded plug is used facing inside, the vent can easily be sealed.

Photo: E. Bellamy

10 Install Electrical Boxes

Add an anchor and tap a depression around it for an electrical box

Attach each electrical box to the anchor with two screws

Be careful to put anchor ends parallel to the wall face, and not in too far. The front of the box should protrude at least 1-1/4” beyond the earthbags (32 mm) to match the plaster. Install boxes as the wall is being built. Anchors can be made of 2x4s (5x10 cm) or 3” diameter poles about 7” long (7.5

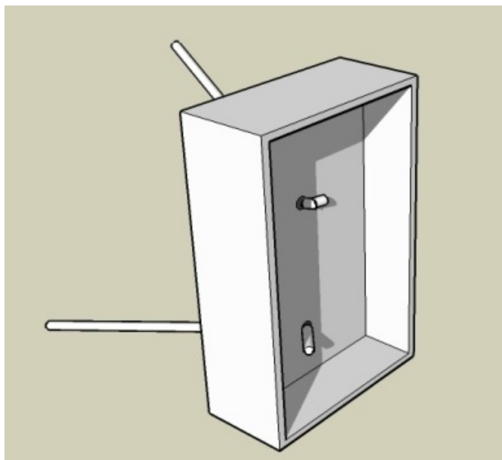
cm diameter 18 cm long) laid between earthbags. Eucalyptus poles can deter termites, or use metal anchors shown in section O4 for doors.

Electrical boxes must be on the same plane as the wall, or the cover plate will not lie flat. Beginning builders can check this by laying an 18" – 24" long scrap of wood (45- 60 cm) next to the box. Use wood the correct thickness.

Use two screws to fasten the electrical box to the anchor to prevent boxes from rotating or jiggling loose over time. Once the boxes are mounted, you can run electrical wire from box to box in the recess between earthbags.

"UF" direct burial wire is one option that is code approved in some areas. You could use regular Romex wire if money is tight and there are no codes. The wires will get covered with about 3" of plaster. Some codes may require conduit, which is better if you can afford it. Conduit provides greater protection and enables you to add more lines in future.

If you remember a new location after the wall is built, sharpen a pole and pound it in before the wall gets too hard. Or use ¼" steel rod (6 mm) to pin the box to the earthbags.



Cut two 7" long (18 cm) pieces of steel rod. Hold the box in place and hammer the rod in at opposing angles so the box won't pull loose. For example, angle one pin up and one pin down. Bend over the last 1-1/4" so it's flat against the back of the box (3 cm). This creates a very secure box. Just remember to have the front edge of the box protrude about 1-1/4" beyond the earthbags (3 cm) to allow for plaster thickness.

Now you're ready to run your electrical wire.

11 Metal Rod Attachments

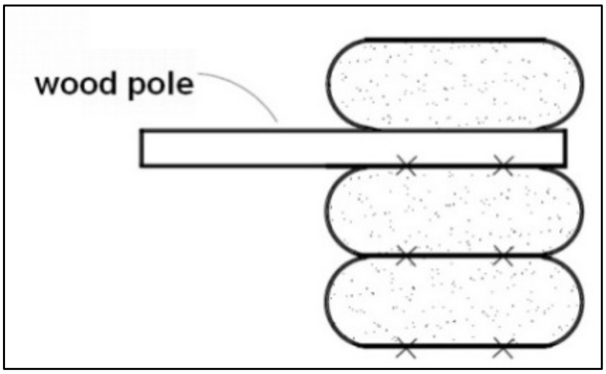
Hammer bent end of steel rod into center of bag

Quarter inch steel rods (6 mm) can be laid between courses or hammered into earthbags as anchors for many things; to hold shelf brackets and nailers; to reinforce and tie cast-in-place concrete elements like countertops or step treads or brick elements like interior walls or footers. Use longer, heavier weight rods or more rods to attach heavier objects or sturdy shelves for dishes, canned food, or books.

12 Attaching Shelves, Seats, or Stairs

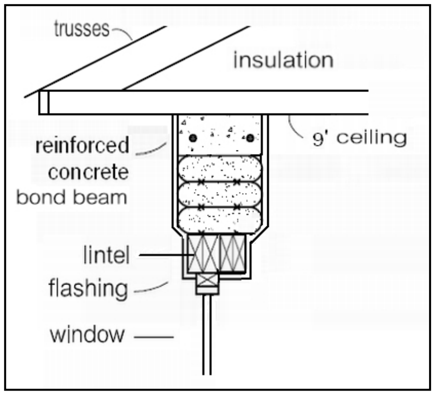
Extend wood or metal supports out of earthbag walls

Supports should extend at least 12 inches into earthbag walls (30 cm). Cantilevered structures or those bearing weight (like cabinets, book or dish shelves, wall-mounted sinks, or wood steps) may need multiple supports sized for extra stresses. Supports in earthbag walls are very difficult to upgrade or replace if damaged in future.



CHAPTER 9 – Lintels and Bond Beams

Lintels support loads above door and window openings and transfer them to adjoining walls. Bond beams tie an entire building together to strengthen walls. The easiest method is to build the bond beam immediately above windows and doors instead of lintels. Vents or transoms take the space above windows and doors and vent heat from buildings.



LINTELS

Buildings with high ceilings may need separate lintels.

ANY LINTEL SHOULD EXTEND AT LEAST 12" PAST THE OPENING (30 CM) to tie it well into the adjacent walls.

Build lintels as box beams, milled or round timbers, concrete, or stone. Box beams are a hollow box of wood, and can support earthbag walls that don't have a gable or high wall above. They are used in cold climates with insulation in their center.

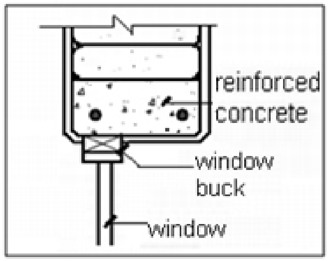
A lintel in an earthbag wall must be stronger than a lintel used in a CMU or double thick brick wall. Because earthbag walls are thick, the earth in each square foot can weigh 30- 40 pounds (15- 20 kg) before plastering for a 15 inch thick (1/10 square meter of a 38 cm thick) earthbag wall. Lintels for openings up to 40 inches wide (1m) can often be safely sized by an experienced builder. Lintels for wider openings or those bearing more than 3- 5 courses of earthbag above should be specially sized. Any opening that is less than 1/6 of the wall length in distance from the corner will carry more stress than in a brick or concrete building, and should have a lintel sized by a designer familiar with earth materials. For alternative lintel materials and sizing advice check in the *Earthbag Design Guide.*

Close-up detail of Eternally Solar's lintel and bond beam system
Photo: Dr. Johnny Anderton of Eternally Solar / EarthBagBuild.com

L1 CONCRETE LINTEL

Build forms strong enough for wet concrete
Use temporary braces to support the rebar

This is the most common type of lintel in many places. A narrow lintel on an earth wall should sit on a strong plate at least 12 inches wide (30 cm) to distribute the weight across the top of the wall.



Where termite problems are common, metal or concrete lintels are safer than wood. In wet climates the tops and sides of window and door frames can have leaking from wind-driven rain. Always create a drip edge and use flashing to keep rain out of window or door openings.

L2 Metal Tubing Lintel

Use two or three sections of metal tubing
Bolt the tubing together every foot (30 cm)

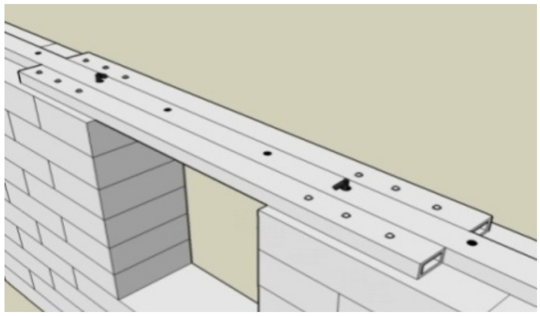


Image: P. Stouter

Reinforced concrete, wood, or metal lintels work well in earthbag walls. A lintel equal in height to one or two earthbag courses is easiest to finish.

A lintel for a 15” (38 cm) wide wall is also easier to plaster if it is at least 12” (30 cm) wide. Plastering will be easiest if the lintel is as wide as the earthbag wall. If a lintel is to be covered with plaster or stucco, tie and nail plastic mesh or chicken wire to the underside of the opening.

L3 Arches

Attach a strong curved form
Tamp each bag into a wedge shape that aligns with center point on the form before placing it
Finish with the center keystone bag

Arches are low cost and attractive, but require some care as loose soils might crumble. Pack arch bags densely with a proper soil mix of clay and aggregates, or use lime- or cement-stabilized earthbags. Pre-tamp bags on the ground to taper the sides. A form box with the right angle helps, or tamp sides of bags into a taper, similar to the way bag tops can be angled for use in a round wall. Tamp from the top with a tamper.

Some builders like to use tubes with stabilized fill to make 'rainbow' type arches. They take less time because they don't need a lot of smaller bags, but use sandy soil and adequate cement, as excess clay can cause failure of rainbow arches.

Tires and barrels the same width as the opening make good low cost arch forms. Larger arches are usually built with forms of wood and plywood, or sometimes small diameter pipe. Forms of recycled bricks, blocks or adobes can be disassembled to remove. Leave the form in place until at least 3 courses above the arch have all cured.

Bottom photo: K. Hart

Bond Beams

The bond or ring beam may be the most important part of an earthbag wall. In hazardous regions it keeps the house together as well as distributing the weight of the roof. Plan and build bond beams carefully. Use a tar or plastic layer under bond beams to protect the earth wall even if the roof leaks.

L4 Reinforced Concrete Bond Beam

Drive vertical rebar pins into top earthbags
Tie them to horizontal rebar
Make a metal or wood form for the bond beam

Photo: E. Bellamy

Always set earthbags level and tamp well before forming a bond beam. Hammer one 24" (60 cm) long rebar pin into each earthbag, leaving at least 5- 6 inches exposed (13- 15 cm). Angle them in different directions to grab the bags well.

Use the right amount of Portland cement, and don't add extra water. A reinforced concrete bond beam is often about 6" high by 12-16" wide. Pre-mark where hurricane ties go and set them in the concrete as you pour the beam, or leave vertical rebar exposed for roof framing. Scaffolding is needed, but a half set can be leapfrogged with enough workers. Start pouring early in the morning when you're fresh to finish a continuous pour with no cold joints.

See general construction books, or in hazardous areas follow an engineer's advice for bond beam size and amount of reinforcement. Overlap rebar 12" (30 cm) minimum and tie well with wire at ends. Many earthbag builders in non-hazardous areas use 12" wide bond beams on standard walls. To size a reinforced concrete bond beam consider the general plan, the wall height, and whether the roof or ceiling joists will be securely nailed to plywood or metal to create a structural diaphragm.

L5 Wood Bond Beam

Use doubled 2x4 or larger (5x10 cm)
Extend beams to end of all piers or walls
Add diagonal braces at the inside of all corners

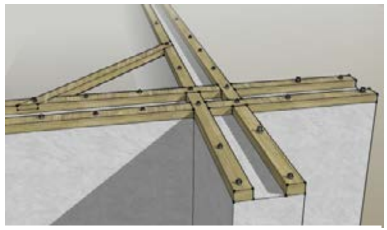


Figure: P. Stouter

Use lap joints of half the beam depth, and block between the beams every 20 inches (50 cm) for doubled wood. Drive rebar pins through holes as for a concrete bond beam. These guidelines from earth building standards developed for India[1] are safest for small buildings where termite damage is limited.

Large timbers may resist insect or mold damage better than small but because wood is often used for low cost, a doubled bond beam of smaller dimension wood may be the most practical. In cold climates, doubled wood bond beams can be filled with insulation. In humid regions it may prevent dry rot if there is flashing on the outside but the wood is open to the air on the inside.

L6 Bond Beam for Curving Walls

Drive vertical rebar pins into top earthbags
Tie them to two pieces of horizontal rebar
Make a form for the concrete of thin, bendable plywood

Use two 24” (60 cm) long rebar pins in each earthbag. Angle them in different directions to grab the bags well.

Building bond beams on curving walls is more difficult than on straight walls. Make forms from quarter inch thick (6 mm) plywood or a sturdy, flexible plastic. Make sure the top of the forms are level. Hold forms in place with wire and quarter inch rebar spacers (6 mm). Use two thicknesses of thin plywood for forms on small roundhouse walls up to about 20’ (6 m) diameter. Use three layers for forms on walls up to 33’ (10 m) in diameter.

Pre-mark for hurricane ties and set them in the concrete as you pour. Add a little cement from the inside to patch up any gaps where concrete would leak out before pouring the whole bond beam. Get extra workers to lighten the load of this very labor-intensive step.

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[1] International Association for Earthquake Engineering and National Information Center of Earthquake Engineering, ***Guidelines for Earthquake Resistant Non-Engineered Construction***, IAEE, Tokyo, Japan and NICEE, Kanpur, India*:* 2004, pages 12 and 14

CHAPTER 10 – Insulated Walls

Most earthen structures such as adobe have been located in hot, dry climates. If you live in a cold climate and want to use a low-cost earth building technique, an earthbag building can provide both thermal mass and insulation. You only need to find what natural insulators are available.

In frame walls insulation fills a cavity inside the structure. Rigid insulation can be applied to the exterior of a structure, but is often more expensive. Structural skins are light sandwiches like SIPs that contain a core of insulation united to exterior structural panels. The details that follow show how to add rigid or cavity insulation to earthbag walls, or attach an extra layer of bag insulation to the structure. Stress-skin techniques with non-structural bags are discussed in the *Earthbag Design Guide*.

Bags filled with volcanic gravel are both structure and insulation. Light clays made with straw or other materials are natural rigid insulation and earth-bermed earthbags can have cheap cavity backfill. Insulations must be chosen for their effectiveness, cost, and suitability to local levels of humidity and pest attack.

I1 STRUCTURAL INSULATION

Fill bags or tubes with light gravel
Lay ties through the walls as you build
Attach a mesh on both sides

Scoria is usually angular in shape and creates fairly stable walls when used in bags. Buy clean scoria, pumice, or vermiculite that doesn't contain sand or silt. Scoria is darker and heavier than pumice. Pumice can have an R-value of 1.8- 2.4, while scoria may be R-0.8 per inch or more. Check a geology website for more details about where these volcanic rocks may be inexpensive or call gravel yards. Usually lighter-weight material has a higher R-value. Even if scoria is not cheap locally, it is so useful to create a thermal break under or in a massive earth wall that buying some may still be worth-while.

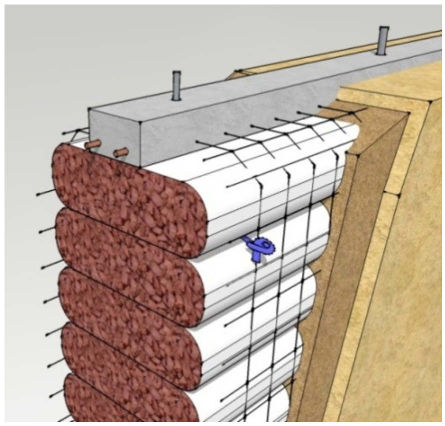


Figure: P. Stouter

Building with light gravel is easier than building with earth because the bags weigh a lot less. Scoria bags are strongest with a mesh-reinforced structural skin or the addition of some mortar anchors to ensure the barbed wire is well anchored to the bags. Because walls do not need to cure, additional insulation layers or plaster can be applied immediately.

SAFETY NOTE: USE CAUTION AND FOLLOW CONSTRUCTION SAFETY GUIDELINES WHEN BUILDING WALLS ABOVE 3' HEIGHT. AT ANY SIGN OF A TENDENCY TO SHIFT, ADD BRACING AND EXTRA VERTICAL REBAR.

About Light Clay Insulation

The hybrid material called light clay combines the strength of clay coated fibers for reinforcement and insulation. Fibers can include natural agricultural waste straw or rice hulls, the air plant called Spanish moss that grows in trees in warm regions, wood chips, or other dried grasses. Clay absorbs odors, moderates humidity levels, and preserves natural materials.

Man-made waste products insulate surprisingly well. Strips of grocery bags can provide about R-3 per inch, and chips of post-consumer foam may be almost as good.

Light clay is made of a thin slurry of clay with aggregates or fibers. Small amounts of clay are needed, and light clay work is relatively easy earth building. Excess clay slip is shaken off. The mix is packed firmly but gently into shape.

Make light clay in the beginning of the summer or at a very dry time. It takes 8 weeks for a 12" (30 cm) thick wall that is open on both sides to dry during the summer. It could take 4 weeks or more for a 4 inch (10 cm) layer to dry completely. Windows should be open and rain kept off any exterior layers. Two thin layers are probably a better idea than one thick one in most climates, especially next to a solid wall.

Videos: ***Vetiver Clay Earthbags***, ***Vetiver Clay Results***, ***Rice Hull Clay***, ***Termite Resistance of Vetiver Clay***

Light perlite clay is strong; photo: P. Stouter

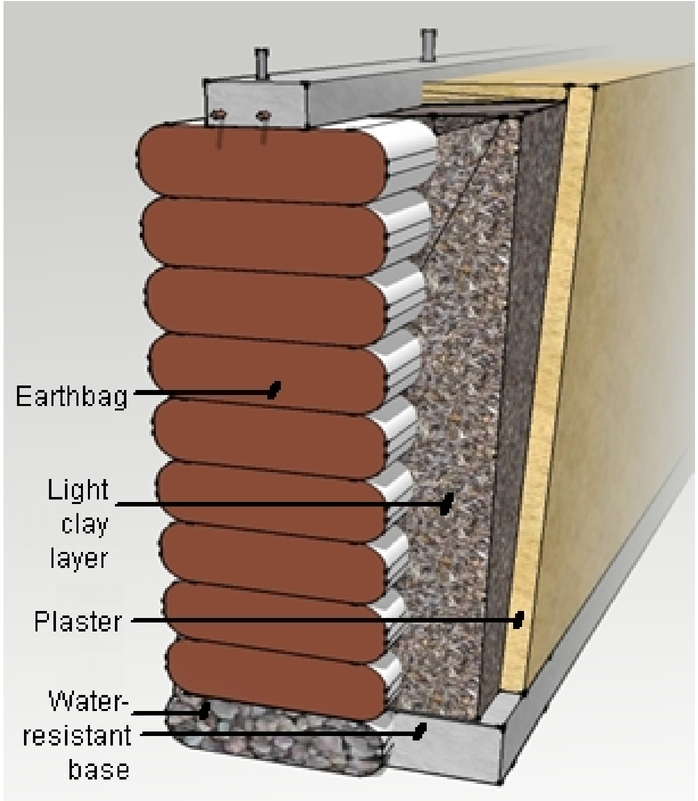
I2 Natural Light Clay

Use a rich soil that is mostly a strong clay
Make a creamy slip of 2 parts clay to 1 part water
Mix 4 parts wood chips or dry straw with 1 part clay slip
Apply a 4- 8 inch thick layer (10- 20 cm) evenly on cured earthbag walls
Pack it firmly together into a form or directly on the wall

Use a water resistant layer 5-10" (12- 25 cm) high made of earth and lime or cement with scoria or shredded Styrofoam.

Spanish moss (right) and wood chips (far right) in clay
Photos: P. Stouter

Wood chips can be green or dry and up to 2” (5 cm) in diameter. They must be bark-free. Straw must be dry and mold-free.



If you are doing a straight wall with a form, move as soon as a section of light clay is in place. Use two vertical boards screwed to a thin piece of scrap plywood that is 30” wide by 18- 24” high (90 cm x 50- 60 cm) for a form. Screw it into nailers prepared in the wall, or nail temporary spikes into bags to hold it in place. Fill in the vertical notches from the form before it all dries.

Light woodchip clay (LWC) is a traditional infill building material in Europe. The R-value varies from 1.6 to 2. In humid regions chips of cedar may resist mold and insect attack better than other chips. Light straw clay (LSC) also makes good insulation but dries more slowly, shrinks more, and takes more work. LSC has more tensile strength and can strengthen exposed corners of other kinds of light clay.

Like sheetrock, light clay with natural aggregates or fibers can be mold damaged if it is soaked. It should not be used next to sources of high humidity like showers and stoves. For exterior insulation it should only be used above the snow drift and water splash levels, under breathable plasters that are well maintained. See the *Earthbag Design Guide* for preliminary test results of R-values of different light clays, or check the Earthbag Building blog for new developments.

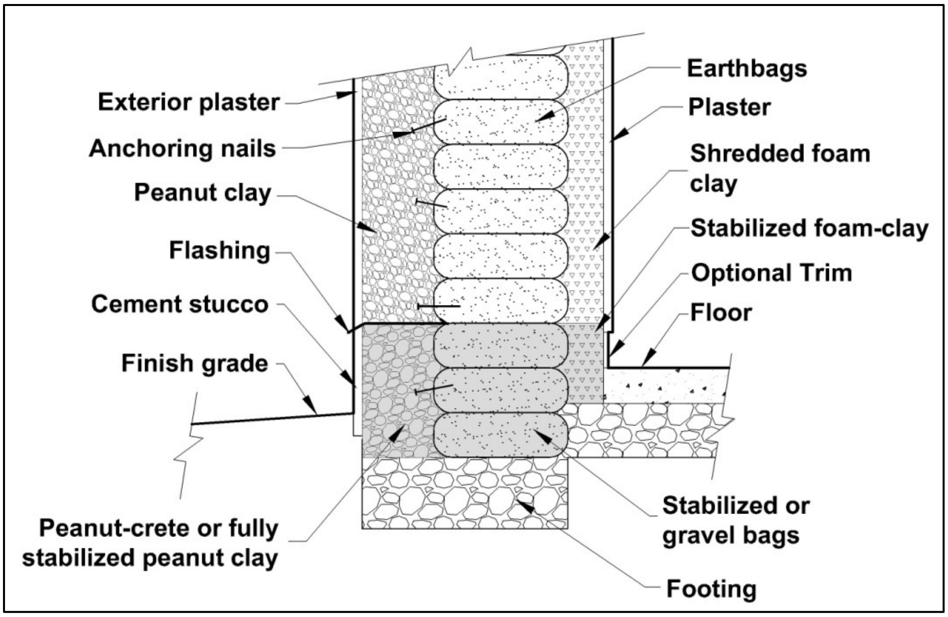
I3 CONVENTIONAL RIGID INSULATION

Screw Styrofoam to earthbag exterior walls
Attach mesh and plaster

This is simple for a straight-walled building. Provide nailers for lathing strip or for larger pieces of Styrofoam. Sometimes large scrap pieces of Styrofoam can be diverted from the waste stream. Large and small scraps of Styrofoam or bead board can be pieced together. Seams between can be filled with a foam clay of small pieces of shredded insulation. This is most cost-effective for owner builders who do not need to pay for labor.

I4 LIGHT FOAM OR TRASH CLAY

Provide a water-resistant base on the outside of an earthbag wall
Hammer nails in bag wall as a foam anchor
Use clay-rich soil to make a creamy slip
Mix 4 or 5 parts shredded foam or packing peanuts with 1 part clay slip
Stir until foam pieces are covered
Apply a 4- 8 inch thick layer (10- 20 cm) evenly on cured earthbag walls
Pack it firmly but gently together



Polystyrene foam (usually white, often labeled 6) can be recycled for high quality insulation, but different types must be used in different locations.

Expanded polystyrene (EPS) building insulation scraps (including Styrofoam) can be recycled for interior use because they contain fire retardants (but avoid breathing dust when shredding or handling). Shipping peanuts and other types of polystyrene foam scraps are flammable but can be safely used on the outsides of buildings. EPS does not absorb much moisture and can be used below grade. Extruded polystyrene (XPS), often used in forms for shipping, has a harder surface but absorbs water. Its R-value will decline with time if installed below grade.

Peanut clay; photo: P. Stouter

SAFETY WARNING:

BECAUSE SHIPPING PEANUTS AND SCRAPS OF FOAM NOT PRODUCED FOR CONSTRUCTION ARE HIGHLY FLAMMABLE AND HAVE TOXIC SMOKE THEY SHOULD NOT BE INSTALLED INSIDE BUILDINGS.

For an exterior insulation layer, peanuts or other polystyrene foams are often available free, and are made of the same material that is R3.6- 4 per inch when solid. Look for a shape of peanut that packs

tightly for a higher R-value when installed. Or mix a portion of shreds with whole peanuts. Just don't get bio-degradable peanuts!

Start foam clay on a vapor barrier on a water-resistant base (for the sake of the clay if not the foam). Foam-crete (foam mixed with Portland cement) or fully stabilized foam clay (but only scraps of construction foam inside) can be used inside or outside. Extend the roof far enough to cover light clay layers, or attach flashing to the wall top to cover the top of the light clay. A small amount of 3-4" (7- 10 cm) long fibers like shredded worn tarps or plastic grocery bags can increase strength for the edges of peanut clay. If necessary, let the foam clay rest until firm before moving the form. Begin the earthen or lime plaster on the surface of EPS light foam clay, add fishnet or chicken wire mesh, and finish the plaster.

Other types of trash make valuable light clay insulation. When strips of grocery bags are mixed in clay they twist and trap air. Preliminary tests showed light clay of grocery bag strips may be as high as R-3 per inch (per 25 mm).

Light clay of grocery bag strips; photo: P. Stouter

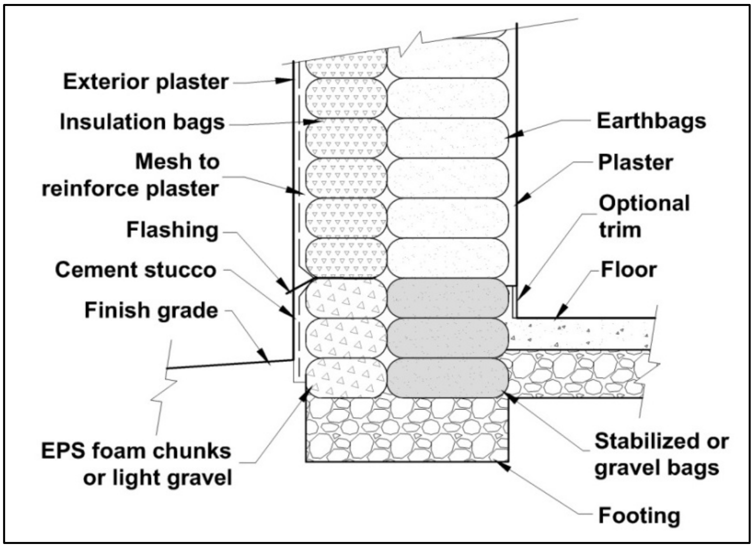
15 DOUBLE BAG INSULATION

Dig a wider footing
Use longer ties in your earthbag building
Fill traction tube sand bags with a natural insulation
Place insulation bags next to earthbag wall
Use ties to attach a reinforcing mesh snugly to the face of the insulation

These traction tube sand bags are typically used to add weight to improve automobile traction on snowy/icy roads. When filled, they provide about 10" of insulation. Tamp them against the earthbag wall to remove insulation gaps. Tie or strap insulation bags snugly to the earthbag wall. Run one strand of barbed wire back and forth to unite insulation bags to structural bags. In hazardous areas where both strands of barbed wire may be needed straight for tensile strength, add extra loops or strands of barbed wire to tie insulation bags to the structure.

Cavity insulation is most often installed in the inside of building walls. But passive solar buildings and thermal mass walls function much better with insulation on the outside of the heavy wall. These narrow tube sand bags allow insulation to be added outside without requiring another wall framework.

Sturdy wire mesh may be enough for a structural base for plaster on a layer of bag fill that compresses slightly or shifts a little under pressure.



Narrow bags can be filled with rice hulls, EPS Styrofoam scraps, light gravels, or EPS packing peanuts. Plastic waste is not very vulnerable to insect or mold damage. Remember, most EPS foam scraps including peanuts are not safe for interior insulation (see page 62- 63). Perlite would be my first choice due to its high R-value (R-2.7x10"=R-27), although the final decision needs to be weighed against other locally available and inexpensive materials.

Top right photo: vexar mesh tubing with foam xps chunks (left), peanuts with food tray scraps (middle), packing peanuts (right); Bottom right photo: vexar with strips of grocery bags

Images: P. Stouter

Scrap materials are often large enough to fit well in cheaper open weave vexar mesh tubes. This stretchy plastic tubing is used for onion bags, and makes firm rolls of scrap foam or packing peanuts 10"- 12" (25- 30 cm) in diameter. Softer materials like strips of grocery bags can be fluffed and used as a cavity fill, but may require a sturdier mesh or lath base for the plaster wall surface.

Rice hulls are still experimental in my opinion, and so the other options are preferred. Rice hulls used as insulation may not be practical unless the whole building can be protected from rain until the plaster or siding is completed. But if rice hulls are the lowest cost material in your area, use them in solid weave poly bags and lay them on a footer high enough to prevent moisture damage. If you live in a region where rodents are a serious problem, seal your insulation cavity carefully or cover them with a wood or metal siding that can easily be lifted to check and replace them if necessary.

Video: [***Insulated Bamboo Walls***]

16 SPLIT BAG CAVITY INSULATION

Sew a seam lengthwise down large solid woven bags
Fill one side with insulation and staple shut
Add soil to the remaining section, place, and tamp

This is begun similarly to double bags but does not need wider footings or as much earth. Divide the large bags into two compartments. It may take more time to fill the bags, but this type of split bag can adjust the exact amount of insulation to the climate, cost, and structural requirements. In a mild climate like New Mexico, about 4-5” of insulation would be needed to reach R-10. In colder climates or seismic risk regions, larger bags could be used. A 12 or 13” earth wall with 6 or 7” of insulation could provide up to R-18 or R-21 with a high insulation value layer like perlite, EPS foam, or rice hulls.

Wall bases can be made of larger bags for strength. For infill like scoria with structural properties, the standard 18” x 30” (46 x 76 cm) bags could have a seam down the middle to use insulated gravel on the outside (50% insulation/50% soil). Lowest courses should use only waterproof insulators like scoria, perlite, or shipping peanuts.

BERMING AND THERMAL MASS

Earthbags are unusually well suited to earth berming. They are not liable to mold damage, and do not need exterior plaster under soil. Gravel bags, sand bags, or fully stabilized earthbags can be built below grade where ground water might harm conventional earthen fills that rely on clay. Raw earthbags can be built in a building with a floor at existing grade and soil added to create a dry raised berm. Often south walls are not bermed, and soil drops to allow some windows located in west and east walls.

A 30 degree sloped berm of dry, light soil to that height around a building is like having an added R-17 insulation layer. In addition, walls covered with a 6’ (1.8 m) depth of earth in cool climates only experience a small range of temperature fluctuations in winter or summer. Earth temperatures deep below grade are usually the average of winter and summer temperatures at the surface.

In temperate regions earth 6' deep may be 48- 55 degrees F all year long (9- 13 C). In the summer, this is cooler than the coolest air temperatures, so a below-grade building can feel much cooler than a normal one. This type of mass cooling is most useful in drier regions where condensation will not be a major problem, or else some surface insulation will be needed on the interior walls.

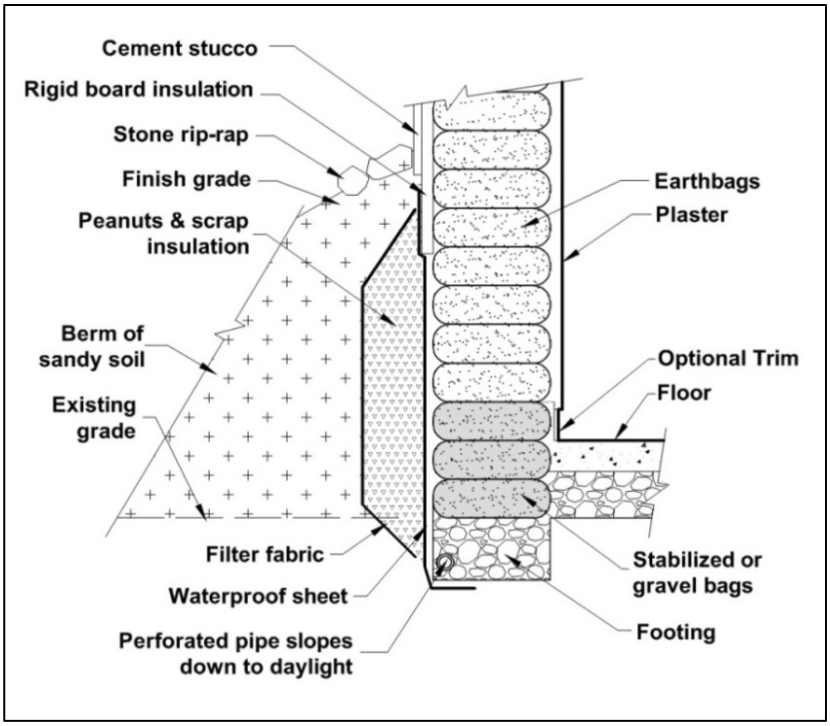
In tropical areas with little seasonal change, below-grade buildings are not much cooler than the night-time air temperatures. But they will be somewhat cooler than buildings that were heated all day by sun and hot air on outside walls.

In very humid regions, heavy materials may collect condensation from damp morning air because they warm up more slowly than the air. Concrete or brick walls may collect enough condensation in warm humid regions that they become moldy, especially if they are bermed. This causes slippery floors and mold unless a room is sealed and continually dehumidified.

Thick earthen walls are not as heavy and will not cause as much condensation as concrete. Earthen or lime plasters on earth walls may be especially helpful to moderate humidity and remove pollutants from air. Cement-stabilized earthbag buildings below grade are not recommended for hot humid areas unless they have an interior insulation layer to prevent condensation.

I7 Insulating Backfill

Provide a good drain to daylight from beneath the footing level
Screw rigid EPS insulation to outside walls on exposed upper walls
Place a waterproof plastic layer next to the building
Backfill with shipping peanuts
Cover the peanuts with filter fabric
Add light soil berm against the building



Use a waterproof sheet under the floor. Provide and maintain roof gutters for taking water away from the building. Stone rip-rap can protect the top of the berm.

If there is no roof gutter, or any water can run down onto the berm from a hillside above, more careful waterproofing will be needed. Extend plastic waterproofing layers as high as possible. Add flashing at the top to prevent seepage into the wall, even in unusual circumstances.

CHAPTER 11 – Roofs

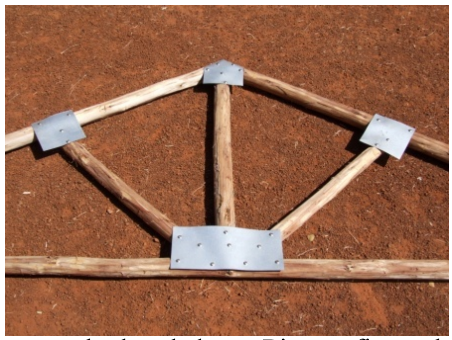
Roofs can be built in many different ways as long as they do not push outward on earthbag walls. Ordinary gable roofs should have a strong collar tie to hold the rafters together and restrain any outward force. Other possibilities are trusses, stick frame, engineered truss joists (TJIs), dome kits, structural insulated panels (SIPS) or poles. Create roof overhangs big enough to protect walls from moisture. A good size for overhangs is from 18” to 36” (45- 90 cm), depending on your climate. Use smaller roof overhangs in hurricane areas to reduce wind damage.

ABOUT TRUSSES

Trusses are one of the best options for building roofs. They are popular because they are very strong, efficient and relatively lightweight. They also create ample space for roof insulation. Trusses can be built before the walls are finished, and installed quickly. Roofing-in early speeds up wall drying.

Trusses are made of multiple short pieces of light-weight wood. Because trusses span longer distances, fewer center walls or supports are needed. If you live where building codes are enforced, then using trusses will make code compliance much easier.

Factory made trusses use milled wood such as 2x4s. But strong trusses can be built of waste wood like pallets that have little environmental impact[1], or of local sustainably grown small diameter poles. These can be gathered in the US from national forests by the truckload for one $25 firewood permit.



R1 ROUNDWOOD TRUSSES

Choose straight, uniform diameter poles
Peel poles
Keep under cover until ready to use
Toe nail joints to hold pieces in place
Screw or nail together with gusset plates

Cut poles about 12” (30 cm) longer than needed so you can remove cracked ends later. Pine or fir work well, and removing bark makes them less attractive to insects. Avoid leaning trees because they will bow and twist badly (‘reaction wood’). Paint the ends of poles immediately after cutting to reduce cracking. Cut end joints with a coping saw, saber saw or Sawzall, or cut V-notches with a handsaw. Protect from rain and freezing as much as possible.

Assemble them in a jig of stakes pounded into the ground or fastened to a bench so that all trusses are the same size and shape. Use 16 gauge sheet metal for cheap gusset plates and fasten with sturdy zinc coated or deck screws. Once trusses are assembled, handle them gently until installed.

If you want, flatten the areas around joints on both sides where gussets are attached. Also, cut (rip) straight edges on the tops and bottoms of trusses to attach roof and ceiling. For straight edges, crown

the poles, snap chalk lines and cut edges with a circular power saw. Use straighter poles so you don't remove too much material. A 20' (6 m) truss should have 4" (10 cm) of wood left after the rip cut.

Roundwood is best for simple designs. More information can be found online[2]. Download truss charts off the Internet for guidelines, or ask local designers for help choosing a truss type. See information in the *Earthbag Design Guide* for help choosing wood that is strong enough for your required span distance.

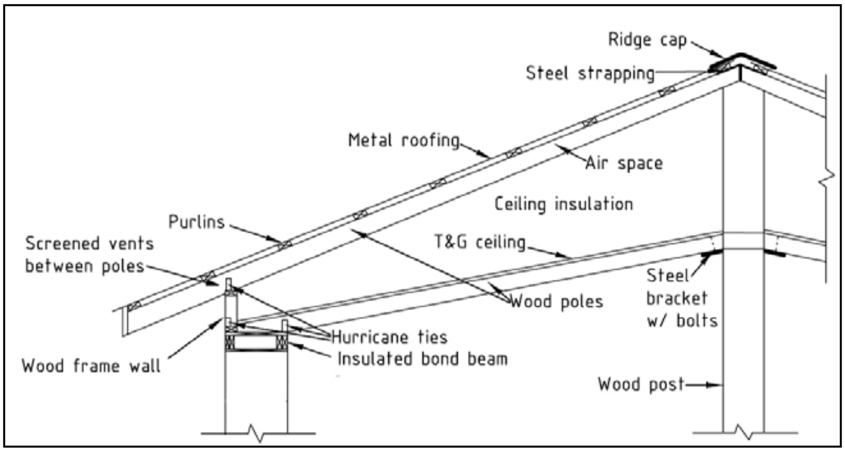
Video: [***Roundwood Trusses***]

R2 Round Roof

Radiate round poles from a center pole or a pre-fabricated steel hub
Use purlins of small diameter on the rafters
Attach shingles or thatch to the purlins

The easiest way to build a small conical roof is to radiate peeled wood poles or joists from a center pole. With support at both ends of the rafters, the roof will not push outward. For a large roundhouse, build a stone, adobe or compressed earth block (CEB) center column or a stone chimney with stove pipe.

Or use a steel ring assembly at the top, with a ring cable on top of the wall. The cable passes through annealed bushings inserted into holes in the rafters. It holds them linked together to counteract outward force of the center weight pressing down.



In cool climates, insulated roofs require more structure. A less expensive type is the double pole roof shown here. This roof has two layers of supports, ceiling joists and roof rafters, both of inexpensive poles. The cost is still reasonable, and it provides a lot of space for insulation. You can use straw bales or poly bags filled with recycled Styrofoam peanuts, perlite, etc. as roof insulation.
Video: [***Thatch Panels***]

[1] More information online about pallet trusses
[2] See Small Diameter Roundwood Trusses for details.

CHAPTER 12 – Plaster

Most earthbag homes are plastered with either earthen, lime or cement plaster. All work well under certain conditions. Use the following information to help you decide what is best for your situation. Whatever materials you choose, a good plaster job can transform rough earthbag walls into a beautiful home, so it is well worth putting in a little extra research, testing, and practice to ensure this process turns out well. Always leave enough time for your plaster to dry or cure before any chance of frost.

Plaster mesh is not needed unless you live in a seismic area or it is required by code. Plaster sticks to earthbags just fine. Not having to use mesh reduces time and labor and materials on a laborious task.

Use tile or slate for bathroom or kitchen areas. Lime plaster can be applied to areas receiving a little less water, wear or soiling. For best water-resistance, a chemical sealant that limits liquid water but not water vapor, like Siloxane, can also be applied to earth or lime.

ABOUT EARTHEN PLASTER

Earthen plaster is the lowest cost, easiest type of plaster to work with. Many of these basic techniques will also apply to lime and cement plaster. Many people find earthen plaster very enjoyable work. They're often pleasantly surprised at how simple it is. The main process is basically smearing mud on the walls, but a little added know-how helps everything go more smoothly.

Earthen plaster is 100% safe, nontoxic and also highly effective at controlling humidity or preventing mold. It can be used on interior walls or on exterior walls with large roof overhangs. In areas with driving rain or deep snow, lower walls are more often plastered with lime or cement plaster.

There are many different earthen plaster recipes, but the basic ingredients are the same – clay or clayey soil, sand or sandy soil, typically a fiber such as chopped straw or manure, and water. Since soil varies widely from one area to another, you will have to experiment to find an optimum mix. Some soils work fine; others require additives and extra work to achieve satisfactory results. Some highly expansive clays will crack severely and should not be used. You may want to find someone who has used local materials for earthen plaster and get their advice. If you need help understanding the soil you have, follow the simple tests in the online eBook *Soils for Earthbag* by Patti Stouter.

Screening sand for plaster; photo: B. Stratton/ Wikimedia

A tray or frame for screening soil helps remove stones and gravel from earth before using it for plaster. Shovel soil or sand at the screen and finer material falls through. Metal mesh works well as a base that different size fishnet or ordinary window screen can rest on.

P1 Test Earthen Plaster

Remove stones, sticks, and leaves from clay and crush lumps
Wet and knead until smooth and stiff
Mix 1/2 bucket of clay with 1 bucket sand
Spread a half inch layer

Soak the clay for a day first, then knead and spread a sample with only clay and sand on some test bags or on a test piece of light straw clay. Let it dry in the shade. When dry, check plaster for cracks or a dusty surface. A humid climate reduces cracking in good clay.

Good plaster

Straw clay block base for plaster samples; photos of tests: P. Stouter

If the surface cracks too much, add sand and/ or fibers. If it doesn't adhere well, add more clay. Many plasters contain as much finely chopped straw or manure as soil. Manure contains very fine fibers. These and wheat paste can be helpful. Get sand from a nearby stream or river, or buy washed sand from a sand and gravel supplier to speed the process. Angular sand increases bonding strength, but never use beach sand or sand high in salt.

You may need many different tests. Be patient. Measure and label your tests carefully. Keep making them until you have a really good plaster. Small cracks like the light sample on the right would be acceptable for the base coat. The plaster on the left was a nice color and a hard surface but cracked too much for a strong base coat.

Right: cracks in base coat samples

Below: poly strips in a base coat plasters

The first coats are less critical. For the finish coat, make a thinner plaster test, with screened dry soil and fine sand.

In very humid climates, use shredded poly bag threads or finely sliced grocery bags as fibers. Cut old poly bags or tarps in 2 inch (5 cm) squares, cover them with water, and run a power drill paint mixer in the liquid for a minute. Or use straw with borax added to the mix to prevent mold.

The bluish clay on the upper right is a good mix. The lower plasters were strong, but lumpy because I forgot to screen the sand. I need to retest with finer sand to be sure it works well.

If you need to add a lot of sand or fibers to a plaster for a large wall, consider trying a different clay to avoid the added preparation work. If you want better plaster, ask a local expert on earth building where to find good local soils.

Three successful plasters

P2 MIX EARTHEN PLASTER

Toss out any stones and break up clumps
Add sand and clay in layers
Moisten the clay and let it soak
Mix well and then add fibers if needed

Do not leave any organic material like roots or decaying leaves in your clay. For finish coats, screen the clay to remove smaller stones or lumps. Very dry clay can be sifted or crushed more easily. Only add water a little at a time. It should be just wet enough to stick to the walls. Plaster that is too wet will crack more. Cover it with a tarp between uses to maintain correct moisture.

For smaller buildings a plastic washing basin or a tub may be big enough, and smaller batches may be quickest to mix. For medium size buildings a tarp like Jessa Turner used in the photo above works well. Lift it to toss the soil and mix. Lay the tarp right next to the wall so it's more quickly available. You can drag what's left to the next location easily. Trample straw for the first coat into the clay by foot on the tarp.

If a cement or plaster mixer is more readily available it can save a lot of time mixing soils. First prepare a clay slip by wetting clay and mixing with a paint mixer on a hand drill. Pour this through a screen to remove chunks. Pour into the mixer with any fibers or additives. Then add the sand, and mix well. At the end add any extra water that is needed.

Photo: B. Stouter

P3 APPLY A BASE COAT

Fill the gaps between bags
Level it out with your hands
Keep it rough to bond with the next coat

This is incredibly simple. It's as basic as smearing mud on the walls. Use your hands for the simplest, most intuitive method, or use a trowel. Small buckets can keep plaster at hand while you work, but many professionals use a hawk (a board or piece of metal with a handle underneath) to hold a supply of plaster ready to use. If it seems easy, try the quicker method used by experienced plasterers of first tossing or throwing the plaster against the wall and then smoothing it.

In this first step, you want to fill the gaps (recesses) between bags approximately flush with the bags. A first coat can also be added around edges of windows and doors. Start gradual curves around the openings. Get the shape right, but if the surface gets too smooth, poke your fingers in or scratch with tools so the next coat will grab well to it.

P4 Attach Mesh Reinforcement

Nail mesh to bags and bucks at openings
Press it into the plaster surface

Earthen and lime plasters stick well to most earthbag surfaces. The area above window and door openings will be easier to plaster with a layer of chicken wire on to help the clay resist gravity until it dries.

The sides of doorways and windows and the lowest part of outside corners are often banged in normal use. At this location any plaster is more likely to crack. A little reinforcing mesh for added strength can save future repairs. Chicken wire, stucco mesh or cheaper alternatives like nylon fishnet will all work. Nail the mesh to the bags and/or the rough bucks. Some builders add mesh directly against the bags before the first coat. I think it's stronger and easier to embed the mesh in the plaster.

Let the first coat dry thoroughly and then you're ready for the second coat of plaster.

P5 Form Drip Edges, Trim, Decorations

Hammer nails at different angles into bags to reinforce trim layers
Anchor and bend extra chicken wire to reinforce edges or thicker portions
Use a stiff clay with a lot of fiber to shape trim

Work this stiff 'cob' mix well into the bag crevices, nails and wire. Allow enough time for thicker trim sections to dry well before adding a second coat of plaster.

Add lots of fiber to sticky clay in the first coat. The fibers are important to reinforce the thicker earth layers and reduce cracking. Either straw or recycled fibers from worn tarps or poly bags can provide reinforcement. Poly fibers will be less likely to contribute to mold damage in very humid climates.

Photos: P. Stouter (plaster by J. Turner)

Thicker trim areas above or around doors or windows can protect walls by directing rain away from vulnerable openings. They can also form an important design element. For earthen plaster, trim does not have to be rectangular, and is pleasant to shape. Let the artist in you emerge, or ask a friend to accent an entranceway.

P6 APPLY A SECOND COAT

Moisten walls lightly before applying a new coat
Add ¼ to ½" thick layers to low areas
Apply a ½" thick coat to level the whole wall
After drying, add more thin layers to fill low spots

The second coat will entirely cover the bags and, for the most part, create a level wall surface. Don't try to fill problem low spots in one pass with a really thick coat, or you'll likely get too many cracks. Some small cracking is fine, but you don't want large cracks that will weaken the plaster. Remember to leave the wall a little bit rough so the next coat will bond. Let it dry very well.

P7 TILE EARTH WALLS

Work small pieces into the wet second coat
Or place tiles in mortar on an almost dry second coat

One way to improve the strength and water-resistance of an earthen plaster is with mosaics. Pebbles, small tiles, or glass chips can create a fine pattern that will resist more abrasion (including rain) than earth alone. For lower parts of outside walls or sink backsplashes, larger tiles or stones can form a permanent washable surface that will not soak up water and remain damp like cement stucco. Set them in about a quarter-inch of lime mortar (6 mm) onto a moistened earth surface. Grout made of either lime or cement can be

used on all earth walls because a relatively small area of earth is in contact with the cement grout. Some lime added to grout mix may allow walls behind to dry better.

P8 APPLY THE FINISH COAT

Moisten walls lightly with a sprayer or mister before applying each coat
Apply a smooth finish coat about ¼ inch thick

The clay soil should be screened to remove lumps, and fine sand can improve finish coat texture. A thin finish coat is easy to apply with rounded pool trowels. Pointed trowels are easier to use near corners. For a rougher, slightly textured wall surface apply this coat with your hands. For really smooth walls use trowels and an extra finish coat.

You can continue polishing the plaster for the more refined results of a 'compression coat'. Mist the wall and apply extra pressure with a trowel, a piece of plastic (like a yogurt lid) or something else smooth. Choose from a whole range of looks, from a slightly nubby rustic look to very polished.

Jessa Turner with bas relief; photo: P. Stouter

Loading a plaster sprayer; photo: N. Scheid

Plastering is an extremely important step that will transform ordinary looking bag walls into a thing of beauty. Take your time, do a good job, and you'll be very happy with the results.

ABOUT LIME PLASTER

Lime plaster made with Type-S hydrated lime works well in most cases for interior and exterior wall finishes. It is not worn away as quickly by rain as pure earthen plasters are. It is the standard plaster used in the traditional whitewashed houses of the Mediterranean, and many other regions.

Lime plasters work well on earth buildings because lime plaster breathes to let heavy clay walls dry better than cement-based plaster, and because small cracks can be sealed with additional coats. This makes lime plaster more forgiving than cement plaster, which turns very brittle over time. Periodic maintenance coats of lime wash will be required, but this will strengthen the plaster. Some areas have lime-rich soils or sands that can be used with earth to create strong natural wall surfaces.

British lime plastering; photo: K. Edkins

P9 Mix Lime Plaster

Mix half a 90 pound bag of lime (41 kg) gently into 4 gallons of water (15 L)
Stir to dissolve and mix well
When ready to use, add two or three 5-gallon buckets (19 L) of clean sand

Lime putty is thick; photo: P. Stouter

Use fresh type-S hydrated lime. If necessary, sift the lime through a screen to eliminate lumps. Once the lime has been stirred into the water, use a mixing attachment for paint on an electric drill to bring this lime 'putty' to a creamy consistency. Lime putty improves with age and is often soaked for months or even longer. Just keep a layer of water on the surface to prevent it drying. Pour this water off before using the thicker putty below it.

Lime plaster that contains sand can last for days or weeks if sealed or kept damp. With the sand add fibers or about a quart of boiled wheat paste. Make sample test patches to determine the optimum mix. Note that 6 buckets of sand are added to the original bag of lime, making a 1:6 mix by volume. Different types of sand affect the color and strength of the final plaster.

USE SAFETY PROTECTION BECAUSE LIME IS CAUSTIC.

USE EYE-PROTECTION AND LONG SLEEVES TO MIX.

WEAR RUBBER GLOVES TO HANDLE LIME PLASTERS – LIME BURNS MAY NOT BE NOTICEABLE UNTIL AFTER DAMAGE IS DONE. VINEGAR WILL COUNTERACT SKIN IRRITATION.

RESEARCH AND FOLLOW SAFETY WARNINGS.

P10 Apply Lime Plaster

Use an earthen base coat to fill gaps between bags and level wall
For the second coat use a mix of lime plaster with some earth
For the final coat use straight lime plaster or add some cement or gypsum

The second coat can contain a 1:10 mix with 2/3 as much finely screened earth added as lime plaster. This reduces the cost of plastering. Since it is workable for an hour or more, it is easy for beginners to apply well. Apply in thin coats until you've obtained the desired finish. Moisten the walls daily with a fine spray in dry climates for about one week and allow adequate drying time before applying additional coats.

Lime plaster is less sticky than earthen plaster, and handles similarly to cement stucco. A hawk to hold the supply and some cement trowels will speed the plastering.

Plasterer's hawk and trowel; Photo: Arpingstone, Wikimedia

Lime plasters can take up to 4 weeks to dry, hardening slowly at first but continuing to harden. Some builders add a small percentage of cement or gypsum (plaster of Paris) to increase initial strength or speed drying.

P11 LIMEWASH

Mix 1 part lime putty with 4 parts water
Paint on lime plaster to whiten and strengthen

Limewash is a thin solution or paint made of slaked lime. It is inexpensive and easy to apply as maintenance coats to protect lime plaster. Limewash gives Greek houses their brilliant white finish.

Do not apply it too thickly or fine cracks may develop. Limewash can be tinted with pigments. If your limewash tends to powder when dry, add a small proportion of latex paint.

ABOUT CEMENT STUCCO

The exterior walls of many earthbag homes are plastered with cement. Cement plaster is not as sustainable as lime or earthen plaster, but it works well in frost-free areas, sheds water, can be painted, and is very popular.

Cement stucco has damaged historic adobe buildings in areas with frost. It may be less harmful on earthbag buildings because of the poly bag layer. Until more is known in areas with frost it is only recommended for use on sandy bag fill that doesn't contain too much clay.

P12 MIX CEMENT STUCCO

Mix equal parts of Portland cement and lime
Add 4 parts of sand
Add water to make a thick paste

Both cement and lime should be fresh and not hardened. This is the proportion for the first or "scratch coat". The second coat has only half as much sand added, or ask local masons or plasterers what the standard mix is. Stucco must be mixed fresh each time it is applied. Make sure it is mixed on a tarp or in a wheelbarrow to keep the mix clean.

P13 Apply Cement Stucco

Put stucco in the recesses between bags
Add 3/8" coat of stucco over entire surface including bags
Gradually fill low areas until the wall is fairly flat
Trowel the stucco smooth with a sponge float for the final finish

As you can see, the process is quite simple, although labor intensive. Add additional coats as needed to achieve the desired look. It boils down to adding a little stucco at a time, but each coat must be at least a quarter inch thick to remain strong (6 mm).

The main keys to strong stucco include: don't add too much water or sand, keep the walls moist to prevent cracking, and leave each coat rough so the next coat will better adhere. Resist the temptation to overwork the surface, or to add thin layers. Once the stucco is on the wall and fairly flat, leave it alone or you may weaken the bond.

Mist recently stuccoed walls twice a day. Always protect plaster from freezing or rapid drying. The latter can be avoided by working in the shade. Allow each coat to thoroughly dry in dry climates before applying the next coat or the plaster may crack. Research the techniques used by plaster professionals in your area and follow their lead. Techniques in rainy/humid regions will vary from drier areas.

More coats and material are required on earthbag than on flat walls made with industrial blocks. For average workers, it will take about 6.5 square feet (0.6 m²) per hour for the entire plaster job. Example: 520 sq. ft. (48 m²) of wall space divided by 6.5 sq. ft. (0.6 m²) /hour = 80 hours of work. A mortar sprayer can speed plastering.
To reduce the amount of cement used on a lumpy bag wall, a stabilized earth mix might be appropriate for the base coat if it is well pressed into the crevices between bags. Volunteers or owners might be able to do this step as well as professional plasterers. Test earth type and cement proportions of 2-5% for a stable, solid material. Earth with some clay will help this base coat to adhere without mesh. The cement is needed to provide a base that will not be too flexible for cement stucco.

Video: ***Hardness Test***, ***Cement Plastering***

Throwing plaster on; photo: K. Hart

CHAPTER 13 – Finishing Details

At this point you can install doors, wood trim, shelving and cabinets, and then stain and varnish any woodwork. Follow general carpentry practices. Connect electric outlets and plumbing fixtures.

Usually the next step is painting your home, but plastered earthbag walls don't need painting or trim. Many builders choose an attractive plaster color and extend it right up to windows, doors and floors. This is another major time and cost saving advantage of building with bags. The last task is the finish flooring, to prevent damaging your new floor. Then it's time to move in and enjoy!

D1 WINDOW FLASHING AND FINISHING

Fasten metal flashing above the lintel and mesh reinforcement
Set windows near outer edges of walls or flush in rainy climates
Add metal flashing on top of the window sill bags
Finish with a waterproof sill that extends past the wall as a drip edge

If your lintel is not as high as a bag course, add a flatter section above it to keep the course level. Tuck or sew the bags more narrowly so that the course will not end up wider than the wall. (Flatter bags become wider, and fatter bags become narrower.) If the wall is more than 4" (10 cm) wider than your lintel, gradually step bags wider to reach the full wall width. This technique is called corbelling. Step a 14.5" wide wall 3- 4" maximum (8-10 cm: 37 cm) at a time.

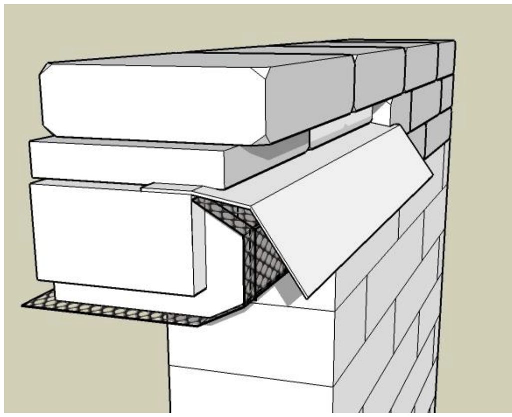


Image: P. Stouter

If the plaster will be earth or lime, fill any depressions and shape drip edges with cob. Use overhangs and/or extended drip edges above windows and doors and below window sills to direct rain around openings and prevent water soaking into the top of plaster. More information about shaping detailing can be found on page 73.

Grout and caulk carefully, especially if flashing nails pierce waterproofing.

ABOUT ON GRADE FLOORS

You could build any type of floor you want in an earthbag home. Building a floor on-grade (on the ground) is the simplest and least expensive. Options include concrete slab, stone, recycled brick and earthen floors. Building this way can save you thousands of dollars on floor joists, plywood, fasteners and other materials. Earthen floors are the least expensive and, like earthen plaster, they're 100% natural, so there's no off-gassing of fumes. Conventional poured earth floors take months to dry before

they can be used, which rules out this option for most in humid and cold climates. Tamped earth floors dry more quickly and can be finished permanently with an attractive oil sealer.

Tamped earth floors are detailed here because they are extremely low cost and user friendly, require no stabilizers, and have minimal cracking. The technique that is summarized below was perfected by Frank Meyer, and may be the best method for making earthen floors. Bill Steen's 30 page *Earthen Floors* booklet is also very helpful.

D2 PREPARE THE SUBFLOOR

Remove all topsoil and debris
Level the area at least 6" below finish floor level (15 cm)
Spread an inch or more of sand under a waterproof layer (25mm)
In cool climates, place insulation

If available, use a thick layer of angular gravel for a capillary break to prevent moisture wicking upward. Top this with filter fabric and a layer of sand. This will protect your 6 mil plastic sheeting moisture barrier. In many rocky soil regions the plastic sheet can also help to prevent radon gas from entering the house. Protect the plastic sheet from damage during construction with a tarp and/ or some extra sand on top.

Natural under-floor insulation options include scoria, pumice and perlite. Plan for the appropriate depth for a high enough R-value. For a 6 inch tamped earth floor this could take 2-3 inches to meet high standards in northern climates. Recycled or waste board insulation may be available. It may save time when walls and plaster are done to mask the walls, posts, or trim at the floor level.

D3 TAMP THE EARTHEN FLOOR

Place 1"- 2" sand on waterproofing
Add a layer of road base 2" thick
Lightly moisten with hose or watering can
Tamp floor

The best material for tamped earth floors is road base, used in many places to build roads. It contains clay and a range of aggregate sizes, and is designed by engineers to withstand years of heavy traffic. Road base is widely available and inexpensive. The same material that works in earthbags (see page 20) also makes a quality floor. Each layer will be one inch thick after tamping by hand or with a mechanized plate compactor. Continue adding layers until 1" below finished floor level.

Install radiant heating one and a half inches (3.7 cm) below the finish level (if it will be used). Radiant tubes are laid in evenly spaced loops. For concrete they are laid at approximately 2" (5 cm) below the finish level, or just under a brick or stone floor. Be careful not to place aggregate directly on the tubes so that tamping will not puncture them.

D4 Finish the Earthen Floor

Level a layer of medium textured road base with screed boards
Wet and tamp
Level a layer of fine textured road base with screed boards
Apply moistened and trowel on
Hand trowel to finish

Screen out large aggregates from the road base using hardware cloth with 3/8" openings for the medium textured coat. Use long screed boards much like concrete workers to level it well. Repeat the leveling process for each additional layer. Make sure that each layer bonds with the layer below. During this process workers can prevent damage by going barefoot and using pads of foam board on which to kneel and walk.

For the fine texture top coat, screen the 3/8" material again using finer 1/8" hardware cloth. This fine mixture can also be applied dry and wetted like all the preceding layers. It is not compacted, but hand-troweled and burnished, using enough water to make it bond and be workable.

Photos: S. Howard

D5 Seal the Earthen Floor

Patch cracks and burnish well
Wait until the floor is bone dry
Apply sealer

Screen the road base through a window screen to make a very fine powder of silt, clay and fine sand. This mixture is excellent for patching and burnishing. It can be sprinkled on, wetted and blended in with the floor. The more patience at this point the better, as burnishing with a pool trowel brings out the natural beauty and character of the earth.

In the summer in warm climates like Texas thorough drying may take only a few weeks. In cooler, moister climates it may take several months. The floor can be used during this drying period.

The best sealer I have found is boiled linseed oil. This is a combination of oil and drying agents that is available at hardware or paint stores. A more natural alternative might be to prepare sun-thickened linseed oil. Pour ordinary linseed oil in a pan, cover it with a sheet of glass above a small air space. With time the oil will oxidize and thicken.

To use either boiled linseed oil or sun-thickened oil, warm it gently on an outdoor burner. When warmed so that it flows more easily, brush on.
For second and later coats add turpentine to the oil after warming it. This building method creates an all-natural non-toxic floor that has relatively low embodied energy. With time, patience and an affinity for getting dirty, anyone can do it. Earth floors can also be decorated with pigments before sealing.

In a very rainy climate, a tile or cement entrance area that will have a rug may be enough to keep water from constantly soaking an earthen floor. Earthen floors that are well sealed are not damaged by occasional spills.

CHAPTER 14 – Starter Projects

EARTHBAG BENCHES

The best advice for those just getting started (after doing some research) is to build something small like a privacy wall, storage shed or bench out of earthbags. Earthbag benches are very easy to make, inexpensive, durable and low risk. Very little can go wrong, and they only take a few hours to build. This makes them a perfect weekend project.

Pick a nice relaxing spot and decide on the size and shape. Curves are great and naturally stronger than straight benches. It's best to build on a trench filled with 12" (30 cm) or so of gravel or concrete rubble to drain water away. Use gravel-filled bags on lower courses until you're above the level where snow or rain can cause problems and then use tamped gravel or soil-filled bags on additional courses.

Put barbed wire between courses to prevent slippage and use the wire to connect the bench with an adjacent wall. A bench near a door can brace the wall.

Let it cure and then plaster; either lime or cement plaster will work. In cold climates a bench is a good test for your lime or earthen plaster. Give the seat a water-resistant finish of stone or cement stucco overhanging 3 or 4 inches (8 or 10 cm).

Earthen benches in a performance space; photo: J. Kennedy

Protect the plaster from direct sunlight and wind so it dries slowly and keep it slightly moist to avoid cracking. You can add natural pigments (for cement) to the plaster and create any color, or wait until a cement stucco finish is dry and paint it.

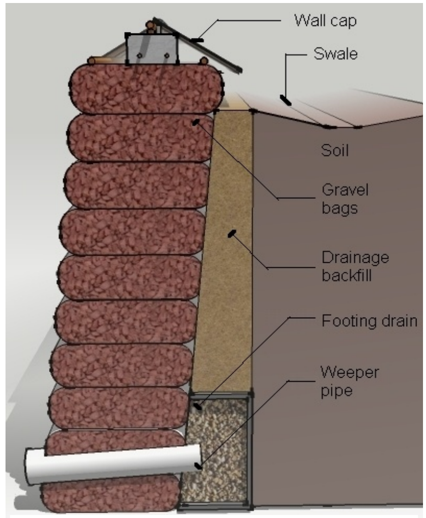
PRIVACY WALLS

Versatile earthbags can combine privacy walls with planters, benches, arbors and trellises to create unique spaces only limited by your imagination. Windows, bottle decorations, storage or display nooks can all be combined with the wall. Add a gate as an accent, or attach a fire-pit.

Provide a 12” trench footing, and start with gravel or sand bags near snow and rain levels. Curve or zigzag the wall for strength or add piers or buttresses 9-15’ (3-4.5 m) on center minimum. Use raw or cement-stabilized earthbags above. Smaller bags (less than 17” or 40 cm wide when empty) are easier to use and strong enough for a 5’ (1.5 m) high wall. Use them on a wider bag base for a 6’ (1.8 m) or higher privacy wall. Seal your wall with plaster and add a wood, tile, or concrete cap on top.

RETAINING WALLS

Make a rubble trench footing
Key gravel-filled bags into the earth
Provide good drainage
Use water-resistant fill



Images: P. Stouter

Retaining walls must be stronger than free-standing walls to support soil leaning against them. Low, stepped designs of multiple small walls are simple and look good.

Start the footing below frost or at least 12” (30 cm) below grade. A deeper footing and soil bermed against the base of the wall will increase stability. Batter, or step each bag back almost a half inch (6 mm) for walls above 4’ (1.2 m) height. Curved designs or zigzag walls are stronger than long straight walls, which need vertical rebar pins, buttresses and possibly a bond beam. Horizontal layers of geo-mesh reinforcement in the slope, a deeper footing or soil bermed against the base of the wall increase stability. Don’t forget barbed wire.

Rubble can be combined with sand or gravel if it is 2-3” (5- 8 cm) chunks or smaller. Gravel or rubble walls can be back-filled with ordinary soil. Stabilized earth walls should be back-filled with a layer of gravel. Wrap filter fabric around the gravel so the drains won’t clog. Moisture in the wall can damage plaster, but more importantly, water pressure built up behind the wall can push it over. Provide weep hole pipes that slope down toward the exposed side, or a French drain with a pipe that runs downhill to daylight at another location. Pitch drain pipes a quarter inch per foot (1:50) minimum.

Use double bags for gravel. Bags that are covered by soil do not need to be plastered. Always protect bags from UV rays if the project will take more than a few weeks. A natural earthen or lime plaster will need a cap like a small roof that overhangs 4” (10 cm) to protect the top of the wall. For cement stucco, provide a waterproof plastic sheet or tar on top of the wall and cap it with a cast concrete coping or stones. Or instead of plaster, add a living wall[1] of plants to beautify and protect the bags.

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[1] Videos of my living wall systems are on Youtube at Living Wall and Living Wall 2.

APPENDIX: Resources

VIDEOS

Building with Bags: How We Made Our Experimental Earthbag/Papercrete House 1 1/2 hr. DVD produced by Kelly Hart. He wanted to build an environmentally sensitive and aesthetically pleasing home at a moderate price, and chose earthbag domes covered with papercrete (recycled paper combined with cement and sand). This honest DVD documents details of the construction, insights gained, and the ups and downs (literally!) of the building process. Several other earthbag homes are also shown. For more information about the house see Photogallery of Our House or Construction Details of Our House. For a streaming video introduction to this DVD click here.

Earthbag Building Video, written, directed and produced by Owen Geiger.

Natural Houses YouTube Earthbag Channel

BOOKS

Earthbag Building: The Tools, Tricks and Techniques by Kaki Hunter, Donald Kiffmeyer, 2004. Earthbag Building is a comprehensive guide to all the tools, tricks, and techniques for building with bags filled with earth.

Building with Earth: A Guide to Flexible-Form Earthbag Construction by Paulina Wojciechowska, 2001. This is the first book published about earthbag building, and still one of the best. Unfortunately it has gone out of print, but is still available used from various sellers at Amazon.

We hope to have the *Earthbag Design Guide* available later this year to answer further questions about how to plan earthbag buildings for strength and sustainability. After August 2011, check the website at http://www.earthbagbuilding.com/resources.htm for availability.

ARTICLES

How to Build an Eco-friendly Earthbag Roundhouse

Insulated Earthbag Houses

Soil Tests for Earthbag
Patti Stouter has expanded and updated her soil testing guide with simple low-tech tests for many types of soil. Using the right soil is very important. After all, earthbag building uses soil as the primary building material, and so you want soil that is strong and stable.

Websites

Earthbag Websites

EarthbagBuilding.com and Earthbag Building Blog have the latest and most up-to-date information.

Earthbag House Plans and Dream Green Homes Earthbag Plans have many sustainable earthbag plans.

EarthbagStructures.com focuses on aid work for the developing world.

Earthbag supplies and resources can be found at http://www.earthbagbuilding.com/resources.htm

Kelly Hart's Earthbag FAQ provides answers to all the most common questions about earthbag building for free. Kelly has compiled about 10 years of questions and answers in one convenient location.

Various Sustainability and Green Building Sites

Really small houses: Michael Janzen's Tiny House Design site.
Fitting architectural quality into small houses: Sarah Susanka's books and articles.
Greywater and rainwater harvesting information: Art Ludwig's Oasis Design
Developing world design information from Engineering Ministries International.
Some appropriate technology and some free earthbag plans at Patti Stouter's Simple Earth Structures.
Building blocks of trash at Harvey Lacey's Recycled Plastic Houses.
Building with shipping containers at Container Home Consultants by Alex Klein.
Information on sustainable architectural techniques at Green Home Building by Kelly and Rosana Hart.
Cob and urbanite construction at Earthen Acres by Danielle Acres.
Mother Earth News Magazine.
The Owner Builder Magazine.

Earthbag Building Guide

Vertical Walls Step-by-Step


In this book:

- Step-by-step directions for building vertical wall earthbag houses
- Detailed information on each major aspect of building earthbag houses
- Shortcuts, tips, tricks and advanced earthbag techniques
- How to make low-cost earthbag foundations with no concrete
- How to build insulated earthbag houses
- Complete information on tools and supplies
- How to make earthbag benches, and privacy and retaining walls for next to nothing
- Over 175 color photos and detail drawings illustrate every detail

"I have built with earthbags for over twenty years, having helped develop the concept with Nader Khalili in the early 1990's. Of all the texts on earthbag building that exist (including mine), I have to say that Owen Geiger's Earthbag Building Guide is by far the most thorough, detailed and technically useful book on the subject yet to emerge. I will be referring to it often in my own projects and look forward with keen interest to forthcoming titles from this talented researcher." Joseph F. Kennedy, editor The Art of Natural Building and Building Without Borders

"Earthbag construction is the most green and sustainable method of construction that I know of and it just got easier. This book is like having a coach with you on site who shares his wonderful knowledge step-by-step. This is the best investment, in time and money, any Architect, Engineer, Builder, or Home Owner can make. I love this book." Dr. Bill Taha, S.E., President, licensed in 28 states, Precision Structural Engineering, Inc.

"This book is very useful for anyone interested in working with earthbags...even those who have experience, since there are many new and innovative concepts presented. It embraces all aspects of safely constructing vertical earthbag walls, discusses ways to insulate and plaster them, and talks about roof options and other details. It even introduces the revolutionary Hyperadobe concept from Brazil! This is a powerful resource." Kelly Hart, owner/developer GreenHomeBuilding.com

"This book will expand our thinking about how we build and where we live. The point-by-point instructions are a wonderful quick reference, and the detailed explanations explain every aspect of each step from foundation to roof." Troy Griepentrog, editor Mother Earth News Magazine

By Owen Geiger – co-author of **Earthbag Building.com,** the largest, most comprehensive website on building with earthbags, and **Earthbag Building Blog,** the most popular blog on earthbag building. Geiger has the largest portfolio of earthbag house plans anywhere – currently over 110 house designs – at **Earthbag House Plans** and **Dream GreenHomes.com.**

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